

# USING ANIMATIONS TO SUPPORT THE UNDERSTANDING OF GEOMETRICAL TOLERANCING CONCEPTS

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## Abstract:

The paper presents general concept and some examples of the new modules of the application *Geometrical Tolerancing* that has been consequently developed by the authors for a couple of years to effectively present and disseminate the ISO GPS system fundamental concepts, definitions, interpretations and rules in technical universities and industry. The package structure and main capabilities are shown and discussed through a few screen shoots. The application starts from the main window in which the user can click on one from the 14 tolerancing symbols or any modifier to open the new window with list of particular symbol/modifier applications. The selection of the case (e.g. roundness, coaxiality of an axis to the common axis, etc.) opens the next window with relevant tolerance and datum indicators attached to the workpiece. There are on screen notes and the context pop-up windows to explain requirements defined by the specification. Selection of the interpretation button at each case window activates the sequence of animations controlled by the user in which she/he is instructed how the datum (or the datum system) is established, next the tolerance zone is presented (running translation and/or rotation of the zone clearly shows its unlocked degrees of freedom) and finally the user triggers the geometrical deviation evaluation. The concepts of the geometrical deviations verification are demonstrated for the selected tolerances. Due many interactive animations enriched by prompts and questions the user has opportunity to control step by step the assessment of the geometrical deviations on the actual parts.

**Keywords:** Geometrical tolerancing, Tolerance indication, e-learning, ISO 1101, GPS

## 1. INTRODUCTION

The geometrical product specification and verification system – the ISO GPS system – developed in ISO by Technical Committee ISO/TC 213 is the only reasonable and unique way to define allowable deviations of actual workpieces from their nominal geometry that do not deteriorate expected functional requirements. On the other hand it was found that interpretations of the tolerance indicators by rules or drawing explanations given in the ISO 1101:2012; ISO 5459:2011; ISO 2692:2006 and other standards [1, 2] are hard for industry and browsing through the hundreds drawings given in the standards is tedious and ineffective.

The successful use of animations to support the education [3] is the challenge for teachers, trainers and tutors. There are some attempts for implementation of the various techniques of dynamic materials such as video or animations in the geometrical tolerancing vocational trainings [4, 5, 6] however our application that has been consequently developed for a couple of years [7] seems to be more mature.

## 2. MAIN COMPONENTS OF THE APPLICATION GEOMETRICAL TOLERANCING

The application starts from the *Main window* in which the user can click on one of the 14 *Tolerance symbol buttons*, the *Datums button* or any *Modifier button* to open the *Case selection window* with the list of cases of its applications. The application *Main window* while the mouse cursor is drag and hold over the *Circular run-out button* is shown in the Fig. 1. The click event opens the *Case selection window* with listed particular applications of the circular run-out (Fig. 2) of a line with respect to datum axis or datum system. The selection of the particular case by the *Line button* opens the *Definition window* (Fig. 3) with the relevant tolerance and the datum indicators attached to the selected workpiece. Any user after a moment can intuitively operate the application due to only three window templates employed in the application. The *Definition windows* for particular tolerances are used to present the key rules for the tolerance indication as well as to explain, how the tolerance zone is established and how the datum (datum system) constraints the spatial placement of the tolerance zone. The on screen notes and the context *Pop-up windows* activated while the mouse cursor is drag and hold over the *Question mark icon* (Fig. 8) are used to explain requirements defined by the specification. On the right edge of each *Definition window* pull down menu with four options (*Specification*, *2D-drawing*, *3D-drawing*, *Interpretation*) is accessible (Fig. 3).

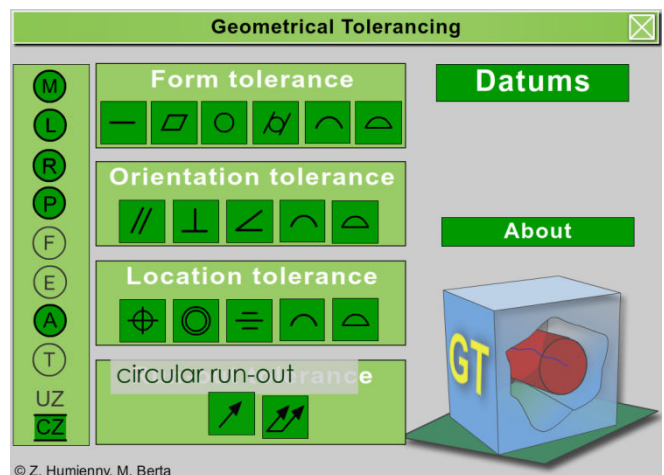


Fig. 1: *Main window of the application Geometrical Tolerancing* – the description of the *Total Run-out button* is displayed adjacent to the button because the arrow cursor is drag and hold over the button

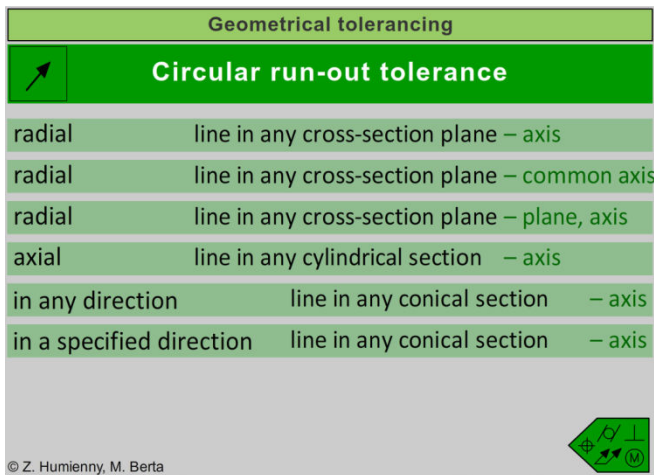


Fig. 2: Case selection window with Line buttons list of the circular run-out tolerance of the extracted line

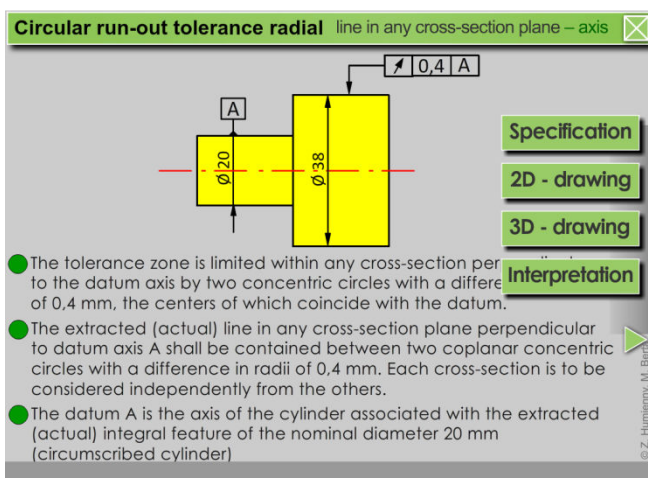


Fig. 3: Definition window of the circular run-out radial tolerance. The expanded pull down menu shown on the right edge guide the user to the next screens

The user in each *Definition window* should trigger the *Interpretation window* by the *Interpretation button* (Fig. 3). to understand deeply the meaning of the particular tolerance specification. Each *Interpretation window* starts from an actual feature (Fig. 4). Next the *Interpretation windows* are used to present inspection methods for a dozen of particular tolerances or to show the tolerance zones for the respective specification. All tolerance zones for toleranced integral or derived features are clearly visualized and then shrunk or expanded to demonstrate particular deviations. The click event on the *Interpretation button* activates series of scenes (a few examples are given in Fig. 3-5) which are switched by the *Forward button* that is available in the bottom right corner of each *Interpretation window*. The prompt line in the bottom of every *Interpretation window* indicates action that will be released by clicking the *Forward button*.

The popular verification method for the circular run-out radial is shown in the application. The scenes in the *Interpretation window* are animated which is obviously not possible to show by the screen shoots given in the paper to demonstrate the application advantages for teaching and learning. For example click on *Forward button* in the Fig. 4 initializes movement of the radially arranged jaws to the

surface which axis is indicated in the drawing as datum feature. The jaws represent self-centring three-jaw chuck. In a while the surface is hold by the jaws that set the datum axis. Next the shaft rotation is activated and a dial indicator is placed in the first cross-section plane. The total indicator reading (TIR) in the first cross-section plane is searched.

The circular run-out requires inspecting circular elements individually. The scene captured in the Fig. 5 illustrates measurement performed in the second cross-section plane. The indicator dial is enlarged in the window left side. Two ring sectors are marked in the dial. The sector marked by indicators g1 and g2 shows extreme positions of the dial gauge pointer observed in currently examined cross-section plane. The values that produce the TIR in the examined cross-section are shown below the indicator dial. The second floating sector in the background indicates the value of the circular run-out tolerance given in the tolerance frame. It is floating to indicate that the circular run-out tolerance limits only difference in the indicator readings. The TIR from the measurement already executed in the first cross-section plane is displayed in the small table in the window top.

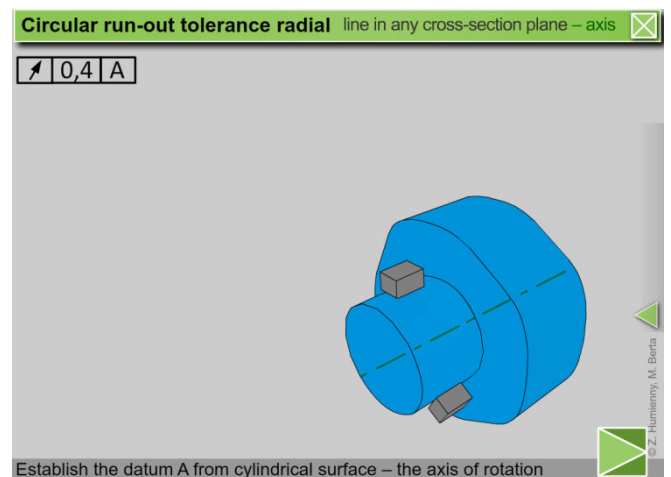


Fig. 4: Interpretation window of the circular run-out radial tolerance – the initial scene with actual workpiece. The click on the *Forward button* initializes the datum axis setting

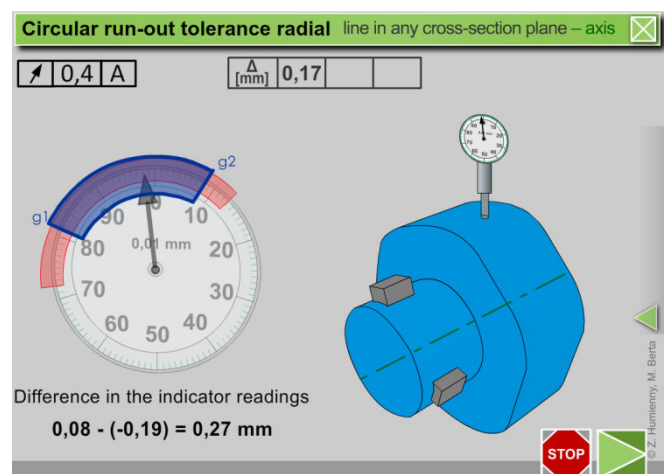


Fig. 5: Interpretation window of the circular run-out tolerance radial – the third scene. The shaft is rotating and total indicator reading in second cross section is registered

In the last *Interpretation window* scene (Fig. 6) the definition of the circular run-out deviation radial is displayed and the biggest value from the TIR gathered in three cross-section planes is highlighted as the deviation for the examined shaft.

It is expected that after study the definitions given in each *Specification window* and some additional information given in the respective *Interpretation window* the user is able to specify tolerance indicator that secures fulfilment of workpiece functional requirements as well as can sketch the draft of the verification plan. The test box with two covered answers is employed in the last *Interpretation window* scene (Fig. 6) to help the user to test her/his competence. The click on the *Test box button* uncovers the right answer that the user should compare with own answer proposed in advance.

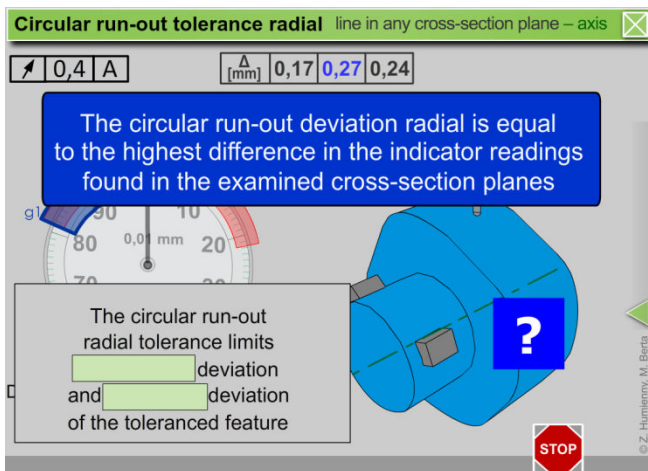


Fig. 6: *Interpretation window* of the circular run-out tolerance radial – the last scene. The value of the circular run-out deviation radial of the examined shaft is highlighted

On the left side of the application *Main window* (Fig. 1) the column with modifiers currently used in the ISO GPS system is available. The second part of this paper is focused on our approach applied for presentation of the material condition modifiers with particular attention on reciprocity requirement. The reciprocity requirement is the new requirement that was first time introduced in the latest edition of the ISO 2692 standard. So it is not wide known and the application enables effective demonstration of its advantages.

Each presentation of the maximum material requirement (MMR), least material requirement (LMR) or reciprocity requirement (RPR) also starts from the *Definition window* (Fig. 7), but next slightly different approach is applied. The effort in the animations is put on presentation that the two requirements – size and geometrical tolerance – are combined into one collective requirement which more accurately represents the intended function of the workpiece.

The *Definition window* for the reciprocity requirement for the external cylindrical feature based on size and orientation (perpendicularity) requirements is accessible in two ways – from the *Case selection window* for the perpendicularity tolerance as well as from the *Case selection window* for the reciprocity requirement.

The RPR is an additional requirement, which may be used together with the MMR to enlarge the size tolerance when the geometrical deviation of the actual workpiece does

not take full advantage of maximum material virtual condition (MMVC). The terms maximum material virtual condition or maximum material virtual size (MMVS) that are crucial for understanding the MMR and RPR concepts are not so obvious for each student. To make it understandable the formula for calculation of the MMVS is given in *Pop-up window* (Fig. 8) with indication, what are the summands of the MMVS. Next the *Interpretation window* with animation presenting verification of the RPR (Fig. 9) clearly shows, what is the meaning of the MMVS. The orientation related envelope with the MMVS visualized by gauge ring – called the maximum material virtual condition – should not be violated by the workpiece material. Thanks to the animation the user may easily understand that the application of the reciprocity requirement for tolerancing of mating features of size enables unique specification of functional requirements with highest allowable tolerances. This due to the fact that priority is given to the parts assembleability and reduction of the production costs.

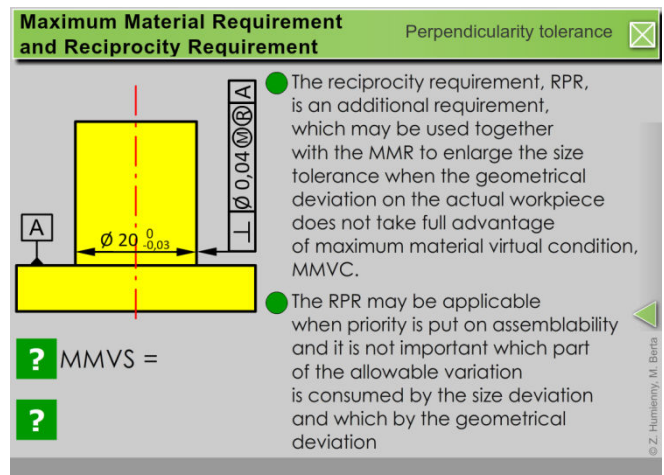


Fig. 7: *Definition window* with the reciprocity requirement for the external cylindrical feature based on the size and orientation (perpendicularity) requirements

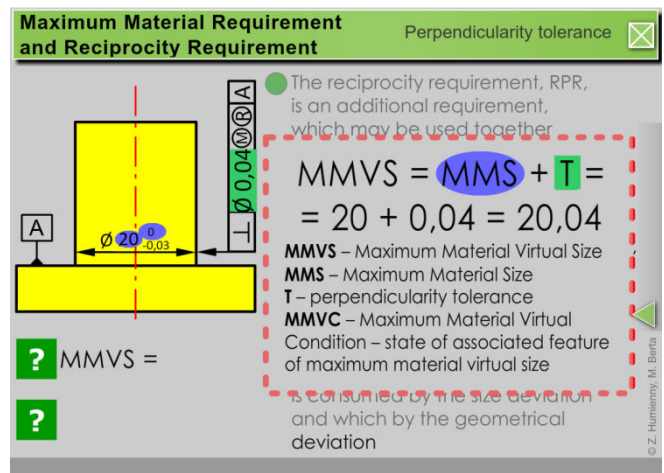


Fig. 8: *Definition window* for the RPR with open *Pop-up window* that explain how maximum material virtual size is calculated and decodes particular acronyms. The *Pop-up window* is displayed because the arrow cursor is drag and hold over the *Question mark button* in the bottom left



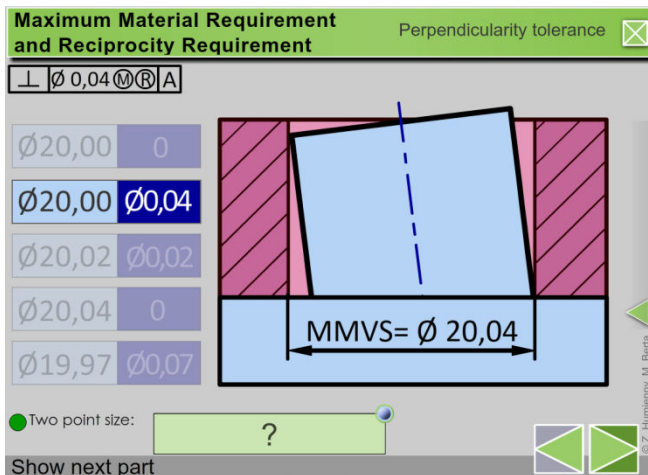


Fig. 9: *Interpretation window* for the RPR (the second from the series of interpretation windows) – the gauge (ring with maximum material virtual size MMVS = 20,04 mm hole perpendicular to its base) represents the mating part

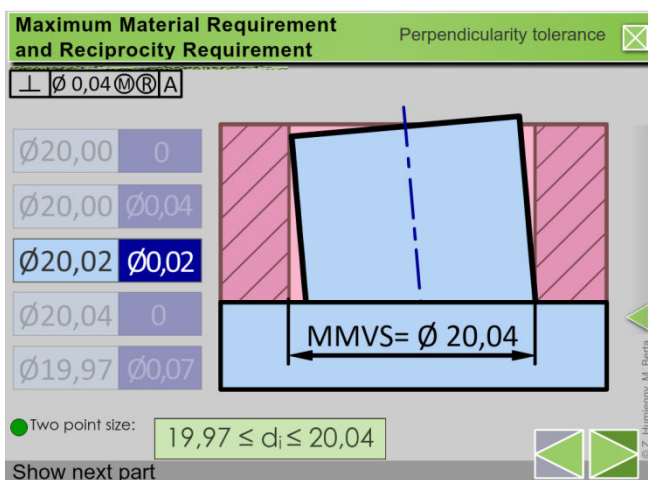


Fig. 10: *Interpretation window* for the RPR (the third from the series of interpretation windows) – the gauge represents the mating part. The answer in the *Test box* (bottom middle) for test question (Two points size:) is disclosed

The idea of the reciprocity requirement is to accept parts, that have small geometrical deviation and thanks to that despite violation of the size limits may be assembled. It means that the size tolerance may be increased by the difference between the geometrical tolerance and the actual geometrical deviation. This is suggestively shown in the application *Geometrical Tolerancing* by series of animations.

The pin of the diameter 20 mm extremely tilted to its base marked as the datum is shown in the Fig. 9. This pin tilting in the second scene of the *Interpretation window* is animated to show that pin with maximum material size may be tilted starting from exact perpendicular orientation up to the deviation limited by the tolerance value 0,04 mm given in the tolerance frame. The prompt text *Two point size:* and covered test box with question mark attracts attention of the user to think about the size limits defined by the reciprocity requirement. The prompt line *Show next part* encourages the user to explore the assessment of the conformity with specification for other actual parts.

The third scene of the *Interpretation window* contains the bigger pin (with the diameter 20,02 mm highlighted in the left). So to fit in the gauge hole the pin perpendicularity deviation shall be equal or smaller than 0,02 mm. Such deviation range is animated in the third scene. The test box with uncovered answer is also shown in the Fig. 10. In the last, sixth scene of the *Interpretation window* the pin with irregular surface is animated to underline, that specification of the MMR and the RPR defines the collective requirement that also limits the toleranced pin form.

### 3. CONCLUSIONS

The proper understanding of the requirements specified according to the ISO GPS system is crucial to correct communication between designers, manufacturing and metrology engineers, especially in the case of car manufactures that deliver or outsource hundreds of parts. Any improper interpretation or application of the tolerance indicators as well as the lack of the tolerance indicators may lead to the controversy between producer and customer during parts verification as well as results in scraps, additional costs and extended time to market.

The effectiveness of the application *Geometrical Tolerancing* has been evaluated through usage during geometrical tolerancing vocational training on multiple industrial groups as well as during lectures at mechanical faculties. A number of the training participants in the automotive and aviation companies stated, that the application with animations is the powerful toll that significantly simplifies and accelerates understanding of the geometrical tolerancing fundamental concepts, principles, rules and indications.

Currently the application contains over 250 interactive animated screens to show carefully selected cases of the geometrical tolerance indications and their interpretations. Due to the modular program structure its further development is feasible and we do it consequently. All animations are created in Adobe Flash CS5. The HTML files are used to control the display of the SWF files in any web browser.

### REFERENCES

- [1] Z. Humienny, "State of Art in Standardization in GPS Area", *CIRP Journal of Manufacturing Science and Technology*, vol.2, pp. 1–7, 2009.
- [2] J.-Y. Dantan, A. Ballu, L. Mathieu, "Geometrical product specifications – model for product life cycle", *Computer-Aided Design*, vol. 40(4), pp. 493-501, 2008.
- [3] E. M. Mayer, R. Moreno, "Animation as an aid to multimedia learning", *Educational Psychology Review*, vol 14, No 1, March 2002.
- [4] www.etinews.com; access May 2013.
- [5] www.symphonitech.com/gdtwiz.htm; access May 2013.
- [6] Z. Humienny, P. Turek, "Animated visualization of the maximum material requirement", *Measurement* vol. 45, Issue 10, , pp. 2283–2287, December 2012.
- [7] M. Berta, Z. Humienny: "Animation as efficient and effective tool for dissemination of the tolerance combination concept for profile tolerance of a surface", in *Didactics of Coordinate Metrology*, W. Płowucha (ed), University of Bielsko-Biala, pp. 15-24, 2012.