

## NEW MULTIMEDIA TRAINING COURSE IN GEOMETRICAL TOLERANCING

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**Abstract:** A new multimedia program “Geometrical tolerances – Definitions and evaluation of deviations” developed at Warsaw University of Technology is presented. The animations and multicolor 3-D drawings are used to effectively familiarize the program user with definitions of form, orientation, location and run out tolerances. Deep attention is paid to application of modifiers. In the practice modules a user has interactive opportunity to assess graphically geometrical deviations on actual parts. So, the user can verify whether he completely understands the concepts of particular geometrical tolerances. This chance is a unique feature among software offered to aid the geometrical tolerancing education. The user can also check acquired knowledge in tests. The program is suitable for self study as well as an aid for lectures at universities or trainings for industry.

**Key words:** geometrical tolerancing, tolerance indication, e-learning, ISO 1101, GPS

### 1. GEOMETRICAL TOLERANCING

The fourteen tolerancing symbols, eight modifiers (fig. 1) and tolerance frames are worldwide used and create unique international graphical language that shall be familiar for designing, manufacturing and metrology engineers, especially in the cases of companies that subcontract or outsource parts. The urgent need for the efficient and broad education in the geometrical tolerancing is noticed all over the world. Particularly in highly competitive automobile industry, because only the proper *Geometrical Product Specification* (GPS) may express in unique way the functional requirements for a product. Next according to the specifications the workpiece shall be fabricated and verified. Finally parts made by many companies are shipped to automobile producer to assembly into properly functioning and reliable car.

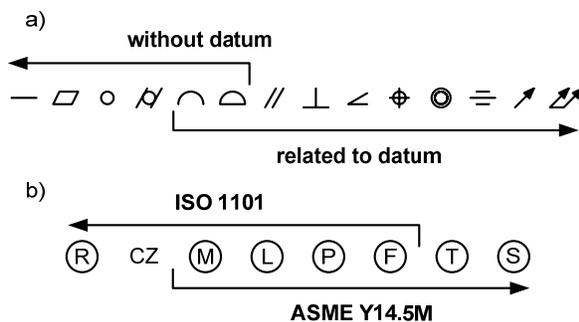


Fig. 1. a) Geometrical tolerancing symbols;  
b) Modifiers.

The rules for geometrical tolerancing are codified in International Standard ISO 1101:2004 and in a dozen of other international standards issued with general head title *Geometrical Product Specification* (Green, 2006; Henzold, 2006; Humienny et al., 2001). Slightly different rules for geometrical dimensioning and tolerancing are applied in USA. The American National Standard ASME Y14.5M-1994 (Drake, 1999; Wilson 2001) establishes uniform practices for stating and interpreting dimensioning, tolerancing and related requirements for use on engineering drawings. The geometrical

tolerancing is playing a major role in the global product development process although some obstacles should be overcome (Prusak, 2006).

### 2. MULTIMEDIA TRAINING COURSE

The geometrical tolerancing is the only powerful tool for clear spatial specification how big deviations from nominal form, orientation and location of workpiece particular features are admissible.

The thorough knowledge of geometrical tolerancing methods helps to ensure their efficient application. The team at Warsaw University of Technology has developed the program *Geometrical tolerances – Definitions and evaluation of deviations* (GT-DED) for which the following objectives have been achieved:

- presentation of the rules of the drawing indication for unambiguous and efficient specification of the geometrical tolerances,
- explanation of the shape and placement of the tolerance zones for tolerances of form, orientation, location and run-out,
- clarification of the importance of constraints imposed by datum or datum system,
- description of all methods for identifying datum features including use of target points, lines and areas on a workpiece,
- elucidation of the benefits and impacts given by modifiers that can be added into the tolerance frames,
- verification whether a program user fully understands the requirements given in a feature control frame by virtual, graphical assessment of the deviations on actual workpieces,
- exercise intensive approach by tests in which user has to find values of the geometrical deviations on actual workpiece and decide whether the workpiece fulfils requirements given in technical drawing,
- enumeration of the differences between ISO and ASME standards.

The general structure of the program *Geometrical tolerances – Definitions and evaluation of deviations* is shown in fig. 2. The block diagram is intentionally

simplified. Beside the navigation left to right many cross links are available to facilitate e-learning e.g. after studying a definition of a particular tolerance (*Definition window*) user can immediately switch to interactive exercise (*Practice window*) to check whether he can graphically assess a geometrical deviation that is limited by the tolerance. If not – the user is not capable to employ the tolerance as a designer or metrologist and he has to restudy the tolerance concept given in definition.

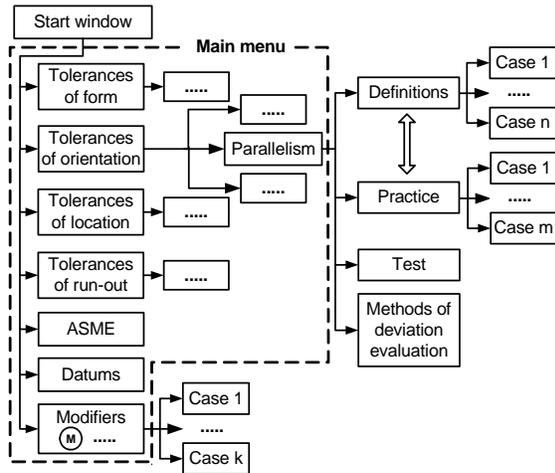


Fig. 2. Block diagram of the program *Geometrical tolerances – Definitions and evaluation of deviations*.

The program offers graphical user interface and can be friendly operated with mouse by clicking particular options that are available in successive windows. The cases of geometrical tolerancing are proceed in pedagogical fashion to guide the user from presentation of the simple specifications up to more complicated requirements.

The program is written in Microsoft Visual Basic 6.0 with employment of the following multimedia techniques:

- graphical visualization – all specification drawings showing ways of indication of tolerances and definitions of the appropriate tolerance zones are made as multicolour 3-D drawings to facilitate clear presentation of the shape and placement of the particular tolerance zone,
- animations I – employed for tolerance indications with modifiers (maximum material requirement, least material requirement, reciprocity requirement, projected tolerance zone) to explain role of modifiers for acceptance of parts for which functional assembly is required. Mating of actual parts with different geometrical deviations is animated,
- animations II – importance of datums order in datum system set up is shown,
- random generation of actual features – for randomly generated profile the user should dynamically i.e. graphically in interactive way, assess the form, orientation, location or run out deviation,
- test with edit boxes – appropriate values of indicated tolerances or deviations for displayed actual features should be typed into boxes,

- selection of background and character colours – the most important information may be distinguished and highlighted.

### 3. GETTING STARTED WITH THE PROGRAM

The main menu window of the program *Geometrical tolerances – Definitions and evaluation of deviations* which appears after the program start-up is marked by dashed line in fig. 2. In the main menu window buttons of particular tolerances of form, orientation, location and run-out are available. The program first time user – which is not familiar with geometrical product specifications – should start from module *Form*. Next, in the module *Datums* he should carefully study concept of datums and rules in which datum or datum system may be indicated. Knowledge of the datums is indispensable to understand tolerances of orientation, location and run-out. More advanced users may explore meaning of modifiers (buttons M, L, R, E, P, F, CZ, T) or look for differences between International Standard ISO 1101:2004 and American National Standard ASME Y14.5M-1994.

If any of tolerance buttons is clicked then the option dialog box (fig. 3) will appear in the centre of the main window. This options dialog box typically contains two sets of radio buttons – function buttons and case buttons. The user should select required option.

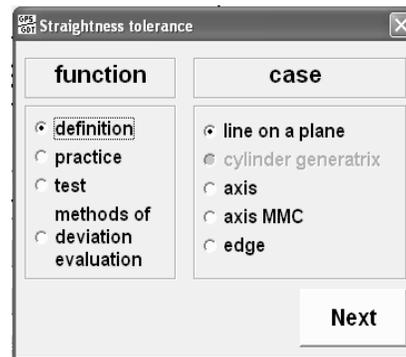


Fig. 3. Snapshot of the options dialog box for straightness tolerance.

The definition windows for particular tolerances are used to present way of indication of selected case of tolerance as well as to explain how the tolerance zone looks like and how the datum constraints determine the spatial placement of the tolerance zone. Two types of the definition windows are used in the *GT-DED* program:

- Static windows with conventional drawings. This type of window contains workpiece drawing with indicated tolerance and 3-D view of actual workpiece with multicolour visualization of the tolerance zone, datum or datum system – if applicable, and actual deviation. Additionally three paragraphs explain how the tolerance zone controls spatial variability of the tolerated feature. The main advantage of such definitions over definitions presented in textbooks is usage of the palette of colours and zoom option that gives opportunity to see details of graphic explana-

tions. The static windows are suitable for all examples of tolerances without modifiers (fig. 4).

- Dynamic windows with animated definitions (fig. 5, 6). The dynamic windows are employed for tolerances with modifiers M, L, R, P and explanation of the importance of datum precedence. The animations are implemented to facilitate understanding the modifier concepts and manner in which datum systems are established for actual surfaces.

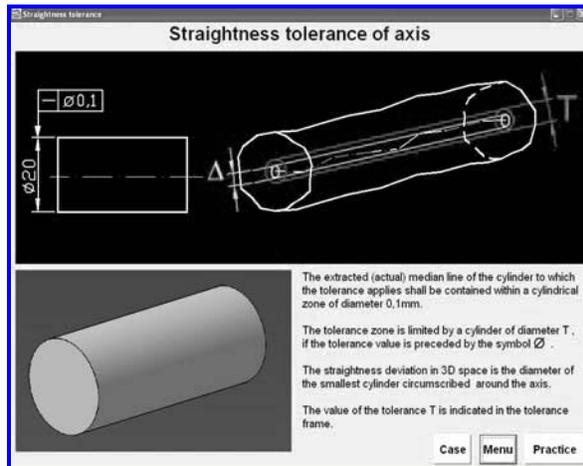


Fig. 4. Snapshot of the window with specification and explanation of straightness tolerance of an axis.

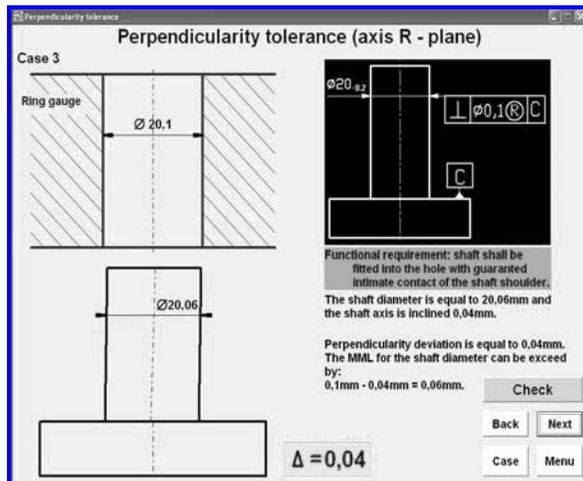


Fig. 5. Window with specification and explanation of perpendicularity tolerance of a line with modifier R. Snapshot before the activation of the animation.

The crucial functional requirement that is reflected by the modifiers M, L and R is *assembleability* of the parts. The M and L modifiers allow a growth and shift in the geometric tolerance originally assigned without adverse effect on the part functionality when actual feature does not contain the most material or least material respectively. The R modifier allow growth in the shaft size or reduction in the hole size when actual feature has smaller geometrical deviation than allowed by the specified geometrical tolerance. All parts that will mate are accepted. Many of these parts may not be allowed to pass

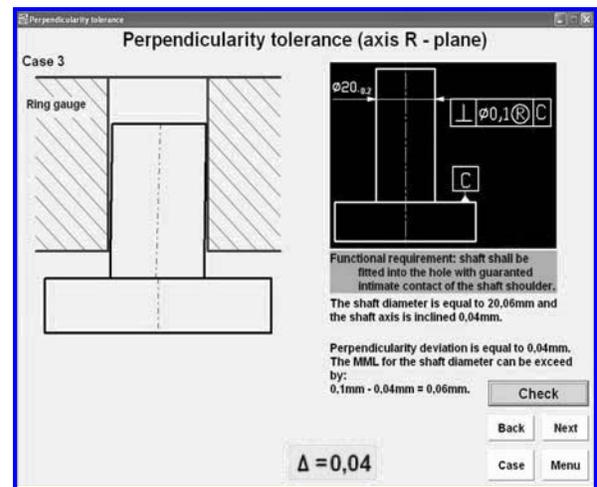


Fig. 6. Window with specification and explanation of perpendicularity tolerance of a line with modifier R. Snapshot during the animation.

the inspection procedure if they had been controlled on regardless of feature size requirement although they may easily have been able to assemble with the mating feature. All three modifiers are carefully defined in just publish standard ISO 2692:2006 *Geometrical Product Specifications (GPS) – Geometrical Tolerancing – Maximum material requirement (MMR), least material requirement (LMR) and reciprocity requirement (RPR)*. It should be noticed that R modifier is for the first time defined in the International Standard and it is not available in ASME Y14.5M.

Virtual checking that reflects assembly process for a set of virtual actual parts is visualized in the *GT-DED* program animation windows. In the top right corner of each window (fig. 5) workpiece drawing with indicated tolerance is given. Below the drawing the functional requirement is explicitly listed. On the left side actual (imperfect) workpiece and virtual gauge are shown. The buttons **Back** and **Next** provide new actual workpieces. Information *Case 3* displayed on the top left corner indicates that on presented snapshot the 3rd virtual workpiece will be examined. By clicking **Check** button the animation is activated (fig. 6) and an observer can find if the current workpiece fulfils the specified requirement. For each animation following information are given:

- What is the value of accepted deviation?
- What is the value of actual deviation?

The students' response during classes proved that animations are very effective in computer aided teaching. They express in very convincing and comprehensive way the concept of modifiers that at first glance has been always seen by the students as mysterious and difficult. The drawing should reflect how a part works and datum selection is key to make it such. Thanks to the implemented animations the user finds that the association of the surfaces used for establishing the datum system should be made one after the other, strictly according to the order defined by the precedence specified in third, fourth and fifth (if applicable) compartment of the tolerance frame.

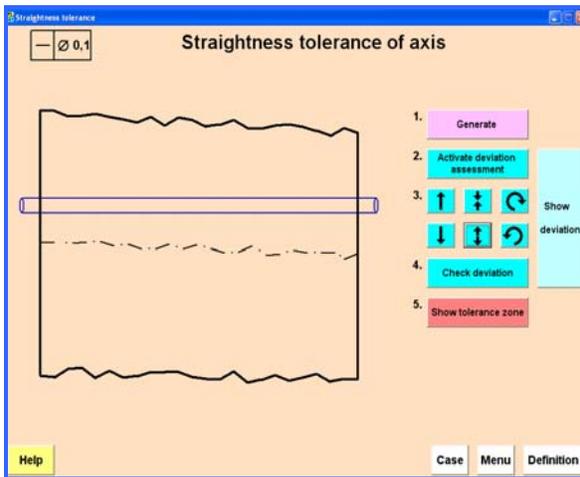


Fig. 7. The practice window for straightness tolerance of axis – an actual workpiece has been generated and cylinder for deviation assessment has been activated.

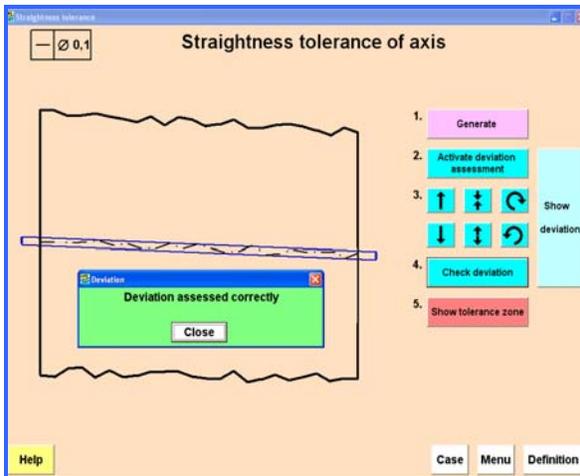


Fig. 8. The practice window for straightness tolerance of axis (continuation of the case from fig. 7) – the actual straightness deviation has been assessed graphically.

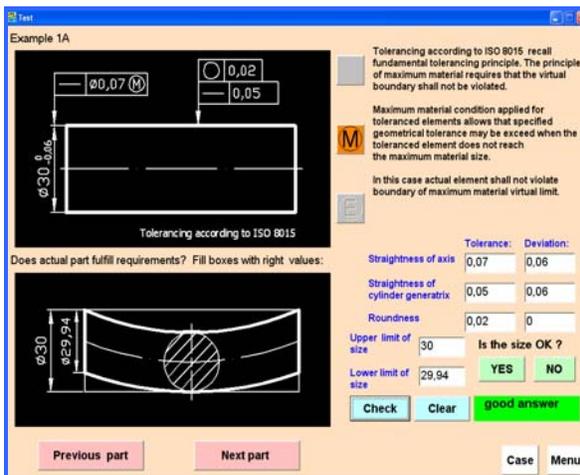


Fig. 9. The test window used for comprehensive verification of competence in area of form tolerances and modifiers application – correct values of specified tolerances and the relevant deviations should be typed into boxes.

The *Practice window* (fig. 7, 8) delivers to the user opportunity for virtual, graphical assessment of the deviation. The workpiece used for the graphical deviation assessment is the same as the workpiece in the *Definition window* (fig. 4), so the user can immediately find whether his is able to apply gained knowledge in practice. The *Test window* (fig. 9) is design for final verification of acquired knowledge. The user should read specified tolerances from the engineering drawing and identify relevant deviations on the actual workpiece.

#### 4. CONCLUSIONS

The geometrical tolerancing is unambiguous and should be applied in industry, especially in modern high technology products that require complete and coherent specification. Tolerancing by dimensions with  $\pm$  limit deviations should not be used because dimensions (except size) are not defined on real workpieces.

The program *Geometrical tolerances – Definitions and evaluation of deviations* was created to introduce the geometrical tolerancing rules for everybody that is involved or will be involved with crating or reading technical drawings. The standardized ways of specification of the tolerances of form, orientation, location and run-out are shown in the program. Beside 3-D multicolour presentation of tolerance zones the program offers also interactive learning through virtual assessment of the geometrical deviations on actual parts. Such option is a new feature among a few e-learning courses offered to support education in the geometrical tolerancing field. So the program enables high student engagement and allows testing the understanding of the geometrical tolerances concepts by particular users.

The program is written in Microsoft Visual Basic 6.0 and its code contain over 100 000 lines that control more than 200 windows with various cases of the geometrical tolerances.

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