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A digital application for geometrical tolerancing concepts understanding

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Abstract

The general concept and main capabilities 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 rules in industry and technical universities are presented. The application structure is shortly shown and discussed through a few screen shoots. The paper is focused on the approach used to present differences between requirements defined by the position tolerance of the two hole pattern without and with maximum material requirement with respect to the datum system created by three datum planes. The other cases of the two hole pattern tolerancing covered by the application are also briefly discussed. It should be noticed that visualizations of deviation measurements by usage of the various measuring methods starting from classical techniques employing indicators and measuring plate or hard gauges up the modern ones like FMM or CMM are just implemented in the application for selected tolerances.

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1. Introduction

There is a vast need in the automobile and aviation industry for univocal specification of the allowable deviations of a real parts geometry from their nominal shape that do not deteriorate demanded performance for each part in the assembly [1, 2]. The geometrical product specification and verification system – the ISO GPS system – defined in the ISO 8015 standard is the worldwide recognized tool for the unique notation of geometrical characteristics. The rules for the geometrical tolerancing indication on the drawings according to the ISO GPS system are given in ISO/TS 17863:2013; ISO 1101: 2012; ISO 5459:2011 and in a few other standards [2, 3]. The fundamental rules of the ISO GPS are contained in the ISO 8015 *GPS – Fundamentals – Concepts, principles and rules*, but for every day designers work the general standard ISO 1101 *GPS –*

Geometrical tolerancing – Tolerances of form, orientation, location and run-out is vital. The initial basis and the fundamentals for geometrical tolerancing are defined in the ISO 1101 standard. It is worth to notice that although the hundred pages of the new ISO 1101 were published in April 2012 the ISO Technical Committee TC 213 [4] is working on its new edition that is scheduled for the end of 2015. Some recommendations for the geometrical tolerancing are also given in the ISO 1660:1987 and ISO 5458:1998 standards. The both are rather old. Their new revised, updated and expanded issues are currently under development in the ISO/TC213.

So currently the information on tools for geometrical tolerancing is spread in dozen documents written in various manners with many figures in each, which is not user-friendly situation. It is tough for industry people to browse through the hundreds of drawings given in various documents. Currently the industry in Poland and

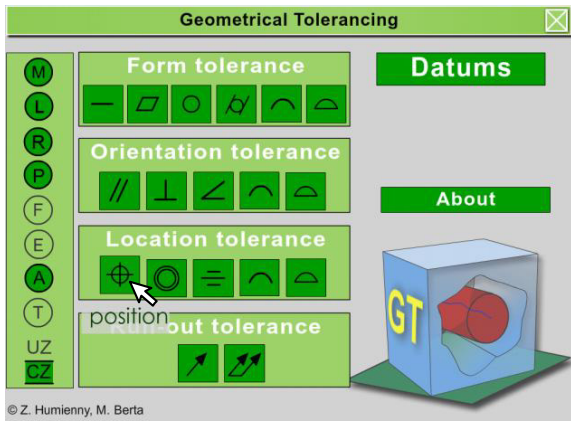


Fig. 1. Main window of the application *Geometrical Tolerancing* – the description of the *Position* button is displayed adjacent to the button because the arrow cursor is dragged and held over the button

also in other countries [5, 6, 7] requires vocational trainings and consultancy for designers, manufacturing engineers and metrology staff. Those three groups of employees, vital for successful production, should understand in the same way the language of graphical symbols used in geometrical tolerancing. The traditional teaching method applied for presenting the geometrical tolerancing rules i.e. lecture with figures given in the slides is tedious for the students and has low training effectiveness [8]. The new training method based on the multimedia animation technology is proposed and implemented by the authors.

2. The application structure

The general structure and main capabilities of the application *Geometrical Tolerancing* are shown in [9]. Below only the short overview is given. The application starts from *Main Window* (Fig. 1) in which a user can

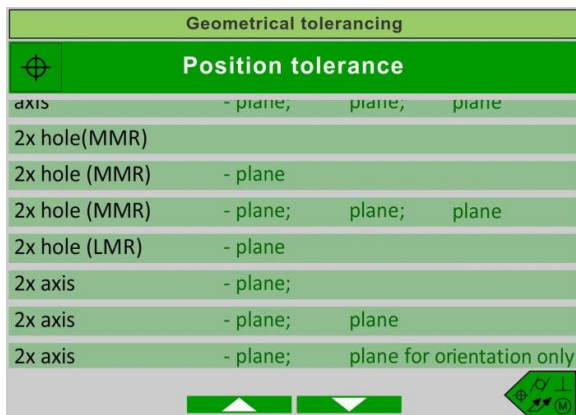


Fig. 2. Case selection window with listed applications of the position tolerance. Each *Line* button opens particular *Definition* window. *Return* button in the bottom right corner secures return to the *Main* window.

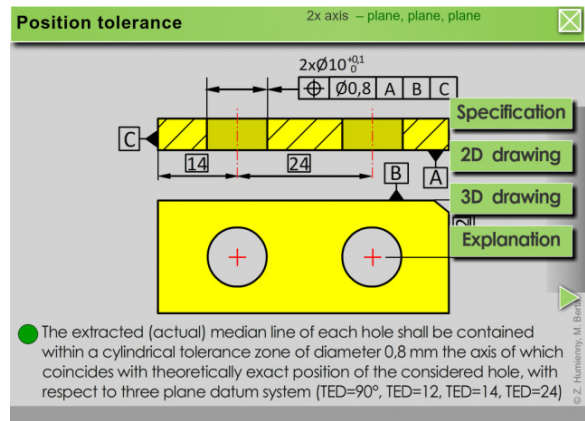


Fig. 3. Definition window of the position tolerance of the axes of the two holes with respect to three plane datum system. The click on the *Explanation* button at the expanded pull down menu shown on the right edge guides a user to the next screens

click on one of the 14 *Tolerance symbol* buttons or any *Modifier* button to open *Case selection* window with list of the particular tolerance applications (Fig. 2). The selection of a case for study (e.g. position of two holes with respect to datum system established by three planes, position of two holes with MMR with respect to datum system established by three planes, etc.) opens *Definition* window (Fig. 3, 7, 13) with relevant tolerance and datum indicators attached to the workpiece. There are on screen notes and small context *Pop-up* windows to explain requirements defined by the specification.

On the right edge of each *Definition* window a pull down menu with four options (*Specification*, *2D-drawing*, *3D-drawing*, *Explanation*) is available. Selection of the *Explanation* button activates the *Explanation Window* with sequence of animations controlled by a user in which she/he is instructed, how the datum (or 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 a user triggers the geometrical deviation evaluation. The geometrical deviation assessment may be shown in two ways: purely as a concept or as a visualization of the selected measuring method. When the assessment concept is presented the appropriate tolerance zone is shown and next the zone is shrunk (or expanded) over the actual feature to show the deviation. The visualizations of the actual measurements covers the classical techniques employing indicators and measuring plate or hard gauges as well as the modern techniques like FMM or CMM.

3. Position tolerance of the two hole pattern

The position tolerance of the two hole pattern with respect to three nominally planar and perpendicular

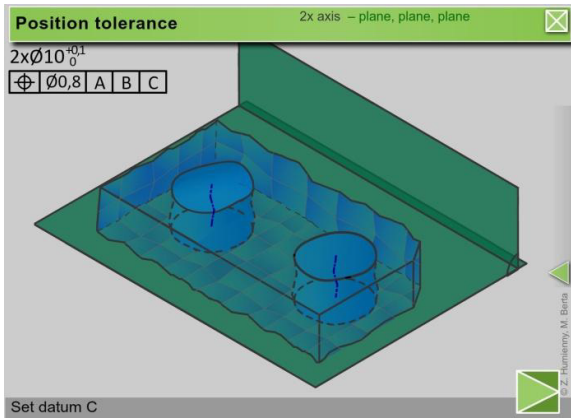


Fig. 4. *Explanation window* – the second scene from the sequence of establishing the three plane datum system for position tolerance of the two hole pattern. The plane establishing the datum B has just appeared and is moving towards datum feature B to come into contact with it

surfaces may be specified as the position tolerance of their axes considered as extracted derived features (ISO 1101) or as the position tolerance with maximum material requirement (MMR) i.e. collective requirement that combines two requirements (size and geometrical tolerance) into one requirement defined by the maximum material virtual size (ISO 2692). The both cases are discussed in the application *Geometrical Tolerancing* and developed animations clearly explain the differences between the specifications.

The way to specify the position tolerance of the two holes regardless of their size with respect to the datum system established by three planes is shown in Fig. 3. First a user should carefully study the manner of the tolerance indication in the drawing and the explanation given below the drawing. Next by the click event on the *Explanation button* she/he should activate series of scenes that show the precedence how the datums are established from actual (extracted) surfaces identified on the workpiece. It is clear that the primary datum shown in Fig. 4 is an associated plane. The screen shoot given in Fig. 4 was taken during animation of the secondary datum search. The plane that respects the orientation constraint from the primary datum is moving towards plate side indicated as secondary datum to get contact with highest points on the actual plate side. The *Prompt line* in the bottom of the window indicates action that will be released by clicking the *Forward button*. The visualization of the establishing the tertiary datum will be released. It is marked by two right angle symbols that the tertiary datum is an associated plane that respects the orientation constraints firstly from the primary datum and secondly from the secondary datum (Fig. 5).

Next two scenes of the animation were created to show that theoretically exact dimensions given in Fig. 3 implicit ($TED_A = 90^\circ$ – perpendicularity) or explicit

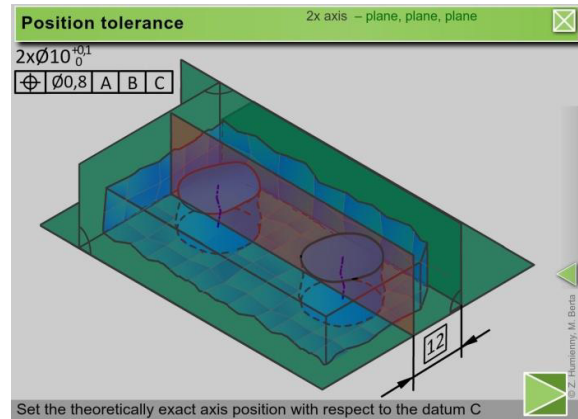


Fig. 5. *Explanation window* – the sixth scene. The theoretically exact distance 12 mm indicates the theoretically exact location of the two hole axes with respect to datum B

(distances $TED_B = 12$, $TED_C = 14$ and $TED'_C = 24$) are indispensable to orientate and locate the tolerance zones for the actual hole axes (the extracted derived features).

The *Explanation windows* are animated to promote the deep understanding of the ISO GPS system rules during teaching and learning. The running animations obviously can not be shown by the screen shoots given in the paper. For example to underline the role of datums and theoretically exact dimensions (TEDs) the planes that set the theoretically exact positions of the hole axes are released from particular datum planes and move with the TEDs' dimensional lines expanding from zero to the respective values given in the specification. The end of the sixth scene with theoretically exact dimension 12 mm that locates the tolerance zone relative to the datum B is shown in Fig. 5.

The *Explanation window* for the position tolerance of the two holes contains eleven scenes. The ninth scene with displayed cylindrical tolerance zones for both holes

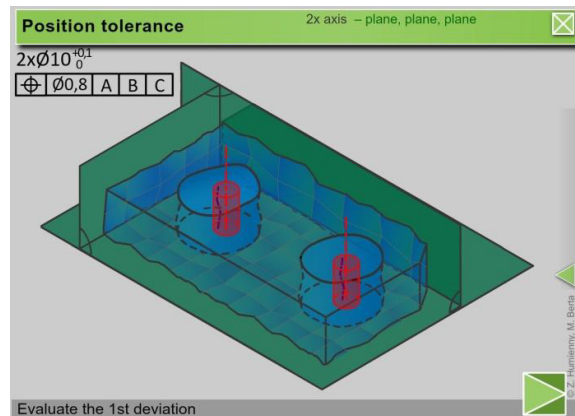


Fig. 6. *Explanation window* – the ninth scene. The cylindrical tolerance zones for both holes are shown

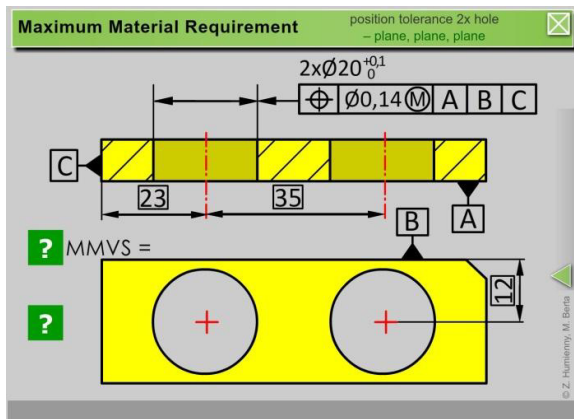


Fig. 7. Definition window with maximum material requirement for pattern of two holes based on the size and the location (position) requirements with respect to three plane datum system

is shown in Fig. 6. At the two final scenes the evaluation of the position deviation for each hole is shown – the tolerance zones from Fig. 6 shrink over the actual axis of each hole – the deviations are equal to the diameters of the cylinders that contain the particular actual axis.

The Definition window for the position tolerance for the two holes with maximum material requirement (Fig. 7) with respect to three plane datum system is accessible in two ways – from the Case selection window for the position tolerance (Fig. 2) as well as from the Case selection window for the maximum material requirement (Fig. 12) that may be activated from Main window by MMR button (Fig. 1). Such duality enables a user to study examples of specification according to preferred order.

The Definition window in Fig. 7 has the same structure as the Definition window in Fig. 3, with identical pull down menu, but in the Explanation window for the MMR slightly different approach is

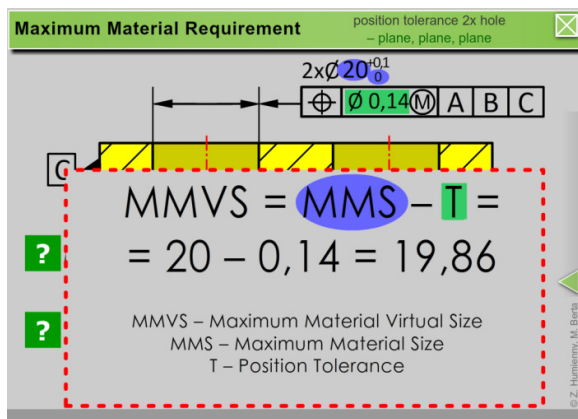


Fig. 8. Definition window for the MMR with open Po-pup window that explains how maximum material virtual size (MMVS) is calculated. The Po-pup window is invoked thanks to the Question mark button

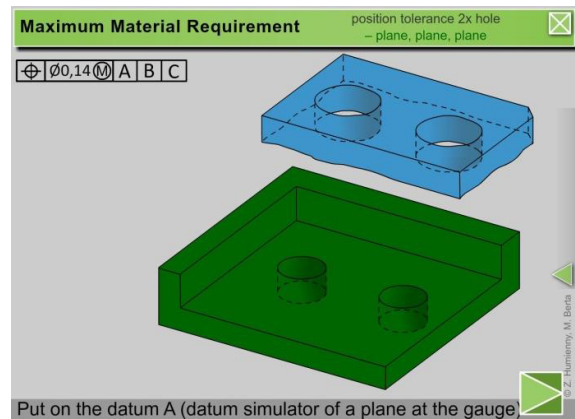


Fig. 9. Explanation window – the initial scene. In the next scenes the toleranced plate will be aligned in the fixture with respect to the datums precedence of three mutually perpendicular datum planes listed in the tolerance frame

applied. The effort in the animations is put on presentation that the two requirements – the size and the geometrical tolerance – are combined into one collective requirement which more accurately represents the intended function of the workpiece.

The application Geometrical Tolerancing makes easier to understand the modifier concepts. The formula for calculation the maximum material virtual size (MMVS) is shown in the Po-pup window (Fig. 8). This MMVS is materialized as diameters of the gauge pins in the verification setup (Fig. 10).

The main goal of the MMR specification is to fulfill assembleability of the parts. So during verification an assessed workpiece should be examined in the way that reflects the assembly process in a production line and the workpiece expected performance. The datum features referenced in feature control frame indicate order in which inspection should align a part to the datum feature

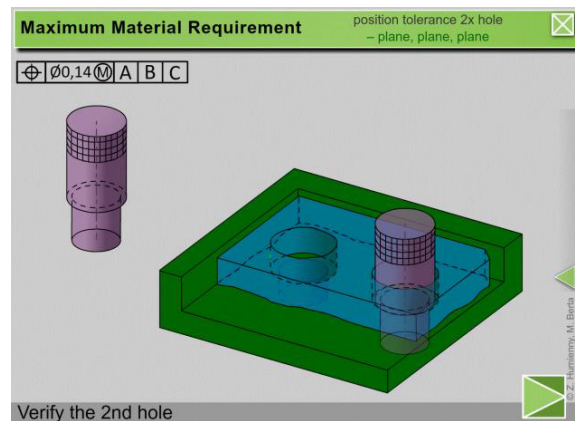


Fig. 10. Explanation window – the last but one scene. The position of the first hole is verified as OK. By click event on the Forward button a user should test whether the second gauge pin will fit into the second hole

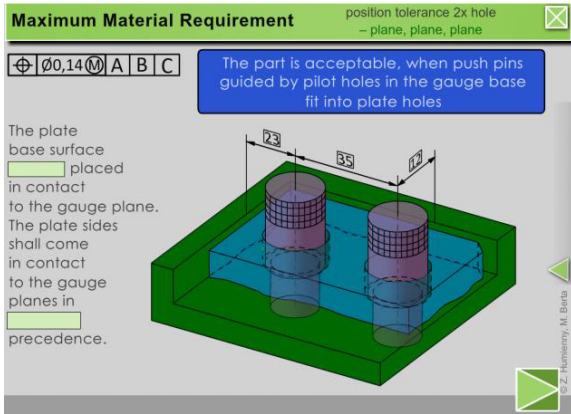


Fig. 11. Explanation window – the final sixth scene. The position of the two hole pattern with MMR with respect to three plane datum system is verified as OK

simulators materialized by planes of the gauge (Fig. 9). The application fix deeply in a user mind that alignment of any produced part strongly depends on its actual features with form and orientation deviations.

The last scene in the Explanation window for the position tolerance for the two holes with MMR with respect to the three plane datum system is focused on summarizing the specification meaning as well as verification whether the application user understands the role and importance of the datum order in the geometrical tolerancing. Such learning objective – the short recapitulation with brief test is applied in the final scenes of many Explanation windows (Fig. 11, 14). The blue information box in the window top makes clear why the holes in the plate are assessed as produced according specification. The text on the Explanation window left side is employed to help a user to test her/his knowledge

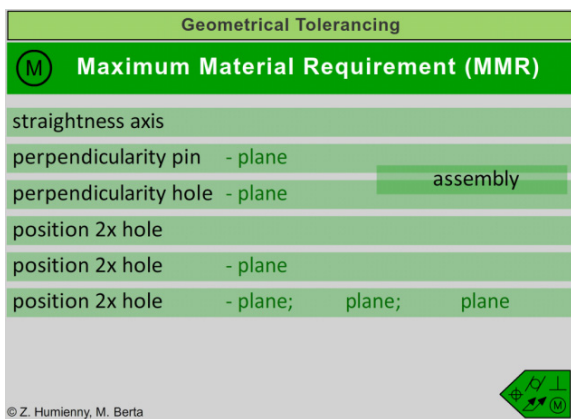


Fig. 12. Case selection window with listed applications of various tolerances with maximum material requirement for the tolerated feature. Each Line button opens particular Definition window. Return button in the bottom right corner secures return to the Main window

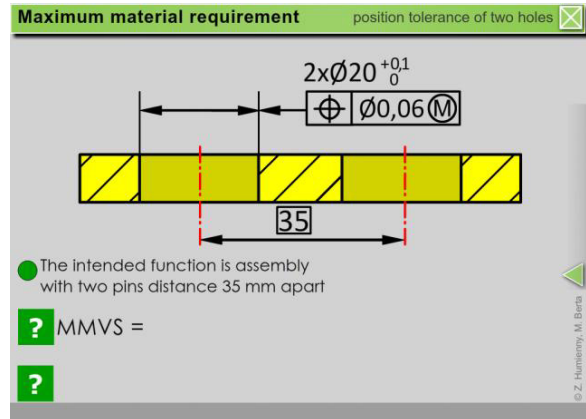


Fig. 13. Definition window with maximum material requirement for pattern of two holes based on the size and the location (position) requirements with no datum

absorption on the requirements for the datum system constitution. There are two Test box buttons that cover right answers – shall and the given – a user shall compare them with own answers proposed in advance.

The application Geometrical Tolerancing gives the opportunity to explore and clarify way to indicate necessary functional requirements by the application of the particular tolerancing symbols to various geometrical features (Fig. 2) or by the application of the particular tolerancing modifiers with different tolerancing symbols (Fig. 12). Such dual approach makes the application usage more relevant to study ways how to limit the geometrical deviations to secure various functional requirements. Currently the six cases of the maximum material modifier are visualized in the application.

The Definition window in Fig. 13 had been released by click event on the fourth case Line button from the

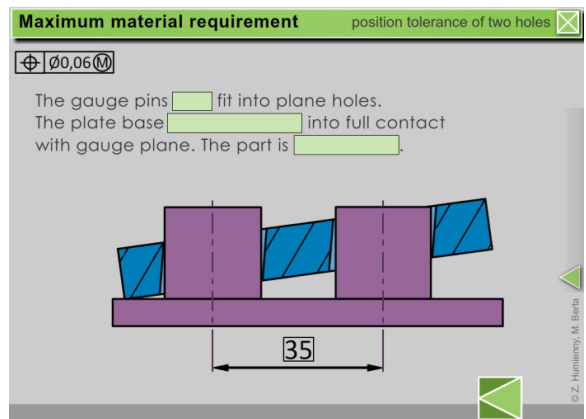


Fig. 14. Explanation window – the final scene. The relative position of the two hole pattern with MMR without any datum is verified as OK. The three Test box buttons that cover right answers should be disclosed to verify correctness of a user answers (shall, need to be, acceptable)

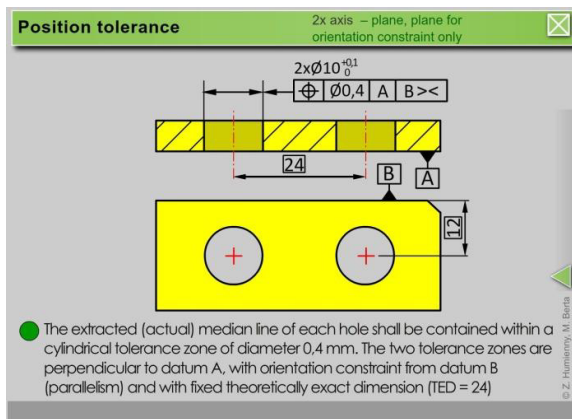


Fig. 15. Definition window of the position tolerance of the axes of the two holes with respect to the two datum plane system. The datum B due to the modifier \gg limits only the orientation for the two cylindrical tolerance zones – the zones shall be parallel to the datum B. The theoretically exact dimension 12 mm is ignored

Case selection window (Fig. 12). The intended function of the plate is assembly with two pins distance 35 mm apart. The verification by the matting gauge is visualized in final scene of the Explanation window (Fig. 14).

The other cases of the two hole pattern tolerancing, respectively with one datum plane, with two datum planes and with the datum plane used only to lock orientation degree of freedom (recently introduced in the ISO GPS system the complementary indication \gg) are also covered by the application (Fig. 2, 15). Such approach – the two hole pattern and various datum configurations enables to show clearly the differences between particular datum meaning.

4. Conclusions

The animations most commonly considered as a part of the entertainment industry are powerful and appropriate in communicating matters of the geometrical tolerancing concepts which often requires illustration the meaning of geometrical variation of actual toleranced or datum features. Influence of the actual feature geometry variations is difficult or impossible to observe directly due to the range of actual changes. In the animations that create virtual reality the feature variation may be enlarged to emphasize the issue of the inherently imprecise manufacturing.

It was found during a number of vocational trainings performed mainly in the automobile and aviation industry that the training with usage of multimedia animation technology attracts the listeners and improves

the learning efficiency. Thanks to that the employees' skills are significantly improved and cost of training is greatly reduced which is welcome by the enterprise management. The students at the Faculty of Automotive and Construction Machinery Engineering at Warsaw University of Technology due to the usage of multimedia animation technology during regular courses and post diploma studies get better scores than a few years ago. The students only after 4 lecture hours supplemented by 4 exercise hours (in the frame of the basic course *Metrology of geometrical quantities and interchangeability at the bachelor study level*) are able to specify and interpret the tolerance indicators for the elementary geometrical tolerancing cases.

The general consensus among those that have viewed the application *Geometrical tolerancing* is that it is successful as a clear and engaging educational tool. The interactive application *Geometrical tolerancing* used as an aid to develop skills and competencies for specification, explanation and verification of the geometrical tolerancing rules and principles gives new opportunities for educators.

There is still the room for further development of the application both for totally new concepts to present meaning of the particular tolerances as well as for development of new animations in already implemented schemes.

All animations are created in the Adobe Flash CS5 and may be displayed in any web browser.

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