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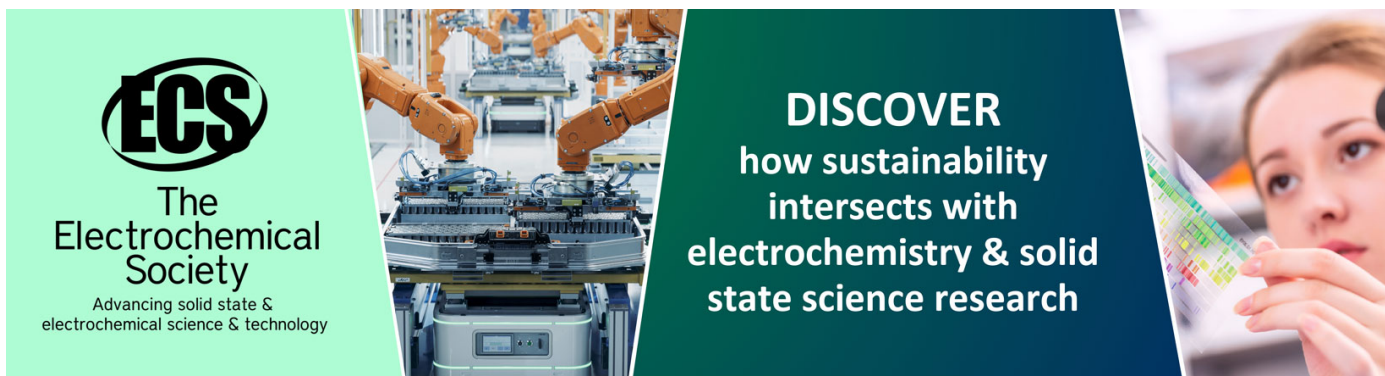
Computer aided explanation of geometrical tolerancing

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Computer aided explanation of geometrical tolerancing

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Abstract. The recent developments of the application *Geometrical Tolerancing* that has been consequently developed by the authors over the last years to facilitate geometrical tolerancing explanation and appropriate application in industry are presented. The application general structure and main capabilities are initially outlined. The paper is focused on the maximum material requirement (MMR), particularly on the difference between the MMR specification for a toleranced feature and a datum feature.

1. Introduction

The ISO GPS system is used to specify how much surfaces of an actual workpiece may differ from their nominal, perfect form, orientation and location [1]. The final step in production of any device is assembly. The assembly of parts depends on the combined effect of an actual size and an actual geometrical deviation of each manufactured feature. The assemblability is well controlled by the maximum material requirement (MMR). Recently the new edition of the standard ISO 2692:2014 *Geometrical product specifications (GPS) – Geometrical tolerancing – Maximum material requirement (MMR), least material requirement (LMR) and reciprocity requirement (RPR)* was published. It is written in the standard that: the minimum assembly clearance occurs when each of the mating features of size is at its maximum material size and when the geometrical deviations of the features of size and their derived features (median line or median surface) are also at their maximum. Assembly clearance increases to a maximum when the sizes of the assembled features of size are furthest from their maximum material sizes and when the geometrical deviations of the features of size and their derived features are zero. It therefore follows that, if the sizes of one mating part do not reach their maximum material size, the indicated geometrical tolerance of the features of size and their derived features may be increased without endangering the assembly to the other part. Unfortunately the quoted statement is very general and thus often misunderstood in industry when the MMR is verified with usage of coordinate measuring machines or any other setup of measuring equipment with separate numerical evaluations of size and geometrical deviation. In such cases the value of geometrical tolerance given in the tolerance frame is often incorrectly enlarged by an additional bonus due to observed sizes of datum features that do not reach their maximum material sizes.

The experience gathered by the authors during consultancy and vocational training in industry indicates that the number of examples of the MMR usage provided in the ISO 2692 informative *Annex A* intended to illustrate application of the rules for the MMR implementation is not sufficient. So we decided to discuss the MMR implication for datum features on a few additional cases in the application *Geometrical tolerancing*.



2. General structure and main capabilities of the application *Geometrical Tolerancing*.

The application *Geometrical Tolerancing* is developed for teaching and training the ISO GPS system fundamental and advanced principles with use of computer simulations, as well as animations at a very large extend [2]. Development of this application is in line to contemporary trends to enrich education by computer visualizations. There are works carried at other universities that developed computer aided didactic environments for teaching applied dimensional metrology [3] or web base course in the field of the measurement uncertainty evaluation [4].

The application *Geometrical Tolerancing* starts from the *Main window*, in which a user can click on one of the 14 *Tolerance symbol buttons*, the *Datums* button, any *Modifier button* or *Size button* to open the *Case selection window* with the list of cases of its applications. The nine *Modifiers buttons* are listed in the column on *Main window* left edge. In the new edition of the ISO 1101:2017 standard set of modifiers is significantly enlarged so the *Etcetera button* in the bottom left corner of the *Main window* is added to open *Case selection window* for other modifiers. Currently over one hundred cases of geometrical tolerances various usage 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 *MMR button* is shown in Figure 1. The click event opens the *Case selection window* where different applications of the maximum material requirement modifier (Figure 2) are listed. Selection of the particular case by the *Bar button* opens the *Definition window* (Figure 3) with the relevant tolerance and the datum indicators attached to the selected workpiece. Only three window templates are employed in the application. The *Definition windows* for particular tolerances with or without modifiers are used to present the key rules for a tolerance indication, as well as to explain how a tolerance zone or virtual condition is established and how a datum (datum system) constraints a spatial placement of this tolerance zone or virtual condition. On the right edge of each *Definition window* a *Pull down menu* with four options (*Specification*, *2D-drawing*, *3D-drawing*, *Explanation*) is accessible (Figure 3). The click event on the *Explanation button* releases series of scenes developed to show restrictions defined by the analysed specification.

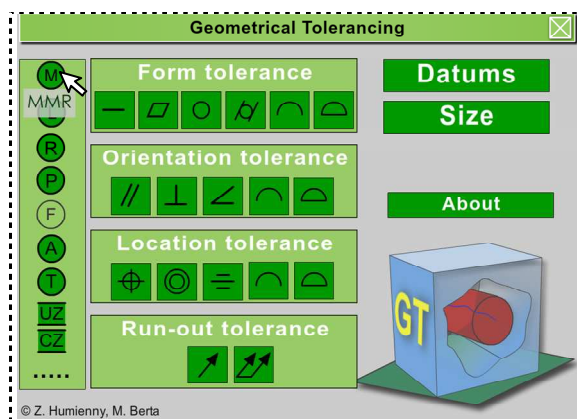


Figure 1. Main window of the application: *Geometrical Tolerancing* – the description of the MMR button is displayed adjacent to the button.

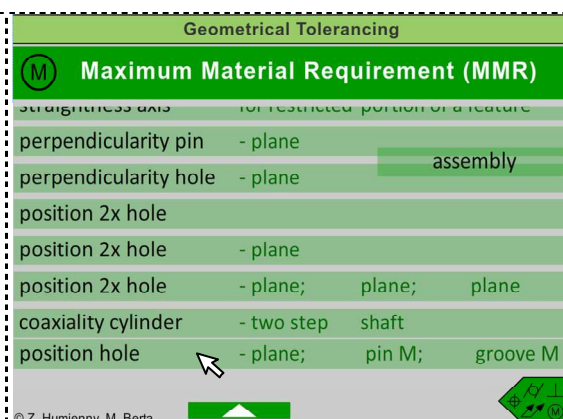


Figure 2. Case selection window with list of *Bar buttons* of the maximum material requirement (MMR) applications. The list may be scrolled to get access to other examples.

3. MMR for internal cylindrical feature based on size and position requirements with respect to the datums with MMR

The *Definition window* for especially created case of the MMR for an internal cylindrical feature based on size and position requirements with respect to a datum system established by the plane, the external feature of size with the MMR (pin) and the internal feature of size with the MMR (groove) is shown in Figure 3. The *Definition window* – as each window in the application – shall be easy to study

and communicative, not overloaded with content. Thus, the context *Pop-up windows* with significant information that clarify requirements defined by the specification are implemented in the application (Figure 4). Sometimes the *Pop-up windows* are applied to help a user to verify whether she/he understands well the concepts of geometrical tolerancing just presented in the application.

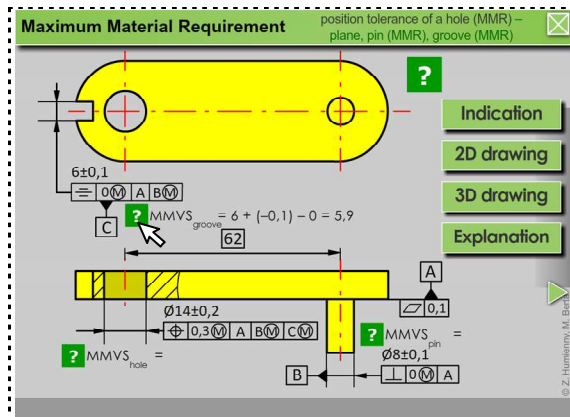


Figure 3. Definition window of the MMR. The click on the *Explanation* button at the expanded *Pull down menu* shown on the right edge guides the user to the next window.

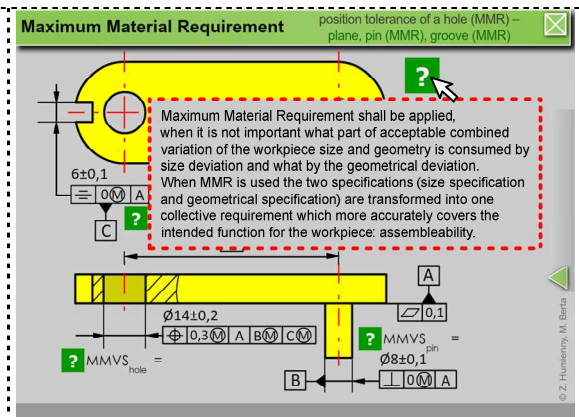


Figure 4. Definition window of the MMR with displayed *Po-pup* window invoked by the arrow cursor dragged and held over the *Question mark* button.

As it was mentioned, after study the *Definition window* a user shall move to the *Explanation window* (Figure 5). This window contains sequence of the sixteen animated scenes that explain suggestively the meaning of specification by verification of a batch of workpieces with especially selected various actual geometry. The navigation between scenes is performed by the *Forward* button placed at bottom right corner of each scene. So a user can adjust display rate of the application scenes according to her/his needs. The command displayed in the *Prompt line* (*Put a toleranced workpiece into functional gauge* in Figure 5) informs what will be demonstrated in the next scene released by click event on the *Forward* button. The functional sizes defined by the tolerances specified for the considered specification (Figure 3), i.e. maximum material virtual size (MMVS) for the datum pin (8,1 mm) and the MMVS for the toleranced hole (13,5 mm) are shown for the visualized gauge. The gauge hole of diameter 13,5 mm is the pilot hole for the pin used to verify position of the toleranced workpiece hole.

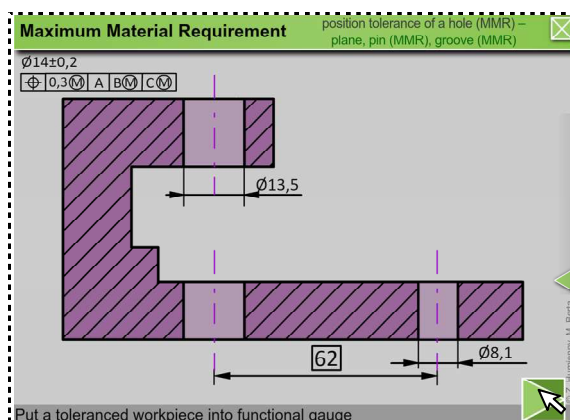


Figure 5. *Explanation window* – the initial scene. Schematic view of the functional gauge for toleranced workpiece is given.

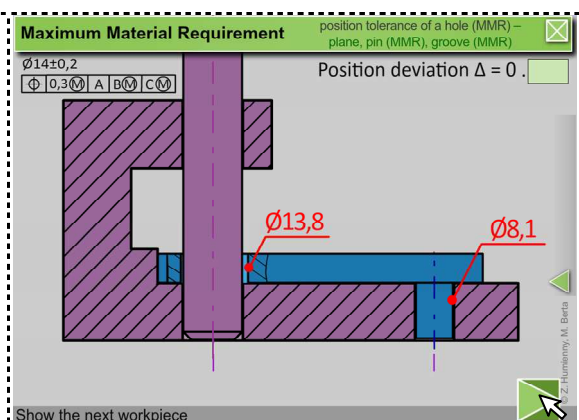


Figure 6. *Explanation window* – the 3rd scene. The workpiece with the toleranced feature and the datum feature at their MMC.

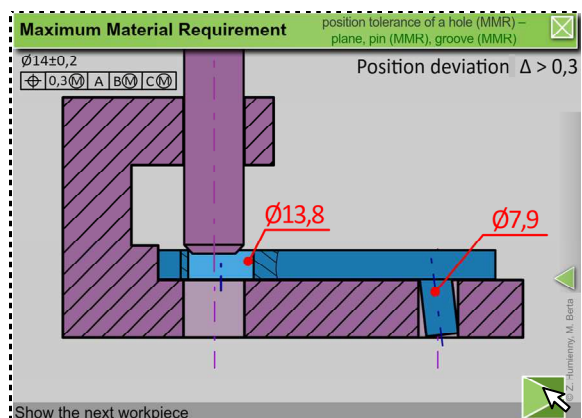


Figure 7. Explanation window – the 9th scene. The tolerated feature is at its MMC and the datum feature is at its LMC, but it is tilted.

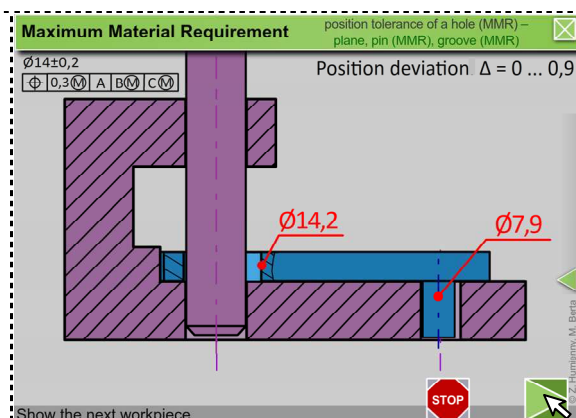


Figure 8. Explanation window – the 13th scene. The tolerated feature is at its LMS and the datum feature is at its LMS.

The first verified workpiece (Figure 6) has the datum pin at its maximum material condition (MMC) and the tolerated hole also at its MMC. Consequently the hole may shift with respect to its theoretically exact position around boundary fixed by the gauge pin. This is clearly visualized in the application, which is obviously not possible to show by the screenshot inserted in the paper.

The workpiece in Figure 7 does not fulfil specification, the gauge pin cannot enter into the tolerated hole. The workpiece datum pin is at its least material condition (LMC), but it does not contribute to the tolerance enlargement because it is tilted.

The workpiece in Figure 8 is used to show that the datum pin with the LMC contributes fully to enlargement of the specified tolerance only in the case when it is exactly perpendicular to the primary datum. The last workpiece shown in the 14th scene is employed to indicate that the surfaces of the produced workpiece have form deviations and the MMR limits the variations of actual surfaces.

4. Conclusions

The Annex A to the ISO 2692 standard gives only six examples of the MMR application with respect to datums with MMR. This is not enough for most of industry people to understand well the MMR concept when MMR is applied to datum or datums in a datum system.

Due to animated visualizations of the tolerated and datum features size and geometry variations it is clearly shown in the application, that the additional bonus tolerance is directly available only when the tolerated feature deviates from the MMC. The bonus tolerance when the datum feature deviates from the MMC is virtually allowable rarely – only for specific configurations of a datum feature geometry.

The application *Geometrical Tolerancing* is an interactive powerful software that makes the complex concepts of maximum material requirement easier to understand for designers, production engineers and quality staff during vocational training. Due to the judicious use of animations the application well supports vocational training as well as teaching at university and is appreciated by students.

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