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COMPLEMENTING AND ENHANCING DEFINITIONS OF LINE PROFILE COMPOSITE TOLERANCE IMPOSED BY ISO GEOMETRICAL PRODUCT SPECIFICATION

According to the ISO Geometrical Product Specifications (GPS), if two or more specifications of the same characteristic are to be indicated, they may be combined as a composite tolerance. Therefore there are no definition differences between the single separate tolerance indicators and their composite tolerance, which is different from the ASME standards. Hereby, the definitions of the combined tolerance which specifies the additional location, orientation and form of tolerance zone are not explicitly defined in the current ISO. It restricts the required definitions of tolerance specifications of a component which are often utilized in practice. However, the required definitions cannot be notated in the technical drawings by using the ISO semantics, because the ISO definitions are insufficient. It causes definition gaps and misinterpretations. This paper focuses on developing the definitions of line profile composite tolerance and suggests a new approach for explicitly defined and function-oriented systematology of line profile composite tolerance. This research is based on the analysis of physical behaviour of geometric feature of a component on a theoretical level. Completed and enhanced definitions in an improved systematology for line profile composite tolerance is formulated which fills the definition gaps and eliminates the deficits in ISO GPS.

1. INTRODUCTION

ISO 1101:2017 [1] is the international GPS [2-12] standard for tolerancing, dimensioning and specifications for geometrical features in design and manufacturing. The basic rules, definitions and corresponding examples of all the 14 tolerance symbols including the line profile tolerance and its composite tolerance are defined in ISO 1101:2017. Another international GPS standard which gives the further informations of line profile tolerance is the ISO 1660:2017 – profile tolerancing [13]. The ISO 5459:2011 [14] is the other important GPS standard for the definitions of datum and datum system, as well as the definitions and utilizations of modifier symbols while using the tolerance indicators. However, the definitions and the corresponding examples of additional

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constraints of location, orientation and form of tolerance zones which the line profile composite tolerance defines, are insufficient and illogical established in the current ISO 1101 and ISO 1660. It restricts the definitions and utilizations of a line profile composite tolerance for a geometrical component which are often used in practice. Nevertheless, those practice required definitions of line profile composite tolerance cannot be explicitly notated in the technical drawing, because some definitions gaps exist in ISO which will cause misinterpretations potentially. Moreover based on ISO, if two or more specifications of the same characteristic (e.g. line profile characteristic symbol) are to be indicated, they may be combined as a composite tolerance. Thus, there are no definition differences between the single separate line profile tolerance indicators and their composite tolerance which is completely different in comparison with another international standard, the ASME Y14.5 [15]. It should be consciously notice that the significant differences while using ISO. The focus of this paper is not on the evaluation of the differences between ISO and ASME, but on the development of a new explicitly defined holistic systematology of a hierarchical structure of line profile composite tolerance in which its definitions are completed and enhanced according to ISO 1101 and ISO 1660. This research is based on the analysis of physical behaviour of geometric feature of a component on a theoretical level and this new approach fills the definition gaps of ISO. This paper also offers corresponding practice oriented examples.

It is to be noted that the previous works [16-23] concentrated more on the mathematical errors in evaluation and measurement technologies of profile tolerance and programming algorithm in 3D CAD system, rather than the development of function-oriented definitions and full systematology with practical examples to complement and enhance the ISO GPS standards, which is the focus here.

This paper is constructed as follows: section 2 describes the state of the art including basic theory and terminologies of line profile composite tolerance and modifier symbol from the current ISO standards. The definition gaps of ISO and its corresponding deficit are analyzed and listed in this section as well. A new holistic hierarchical structure systematology with corresponding examples and definitions are given in section 3. The conclusion is written in section 4.

2. STATE-OF-THE-ART AND DEFICIT

The section 2.1 gives the basic theory, rules and important terminologies and the corresponding illustrations related to the line profile composite tolerance based on the ISO GPS standards. Section 2.2 analyses the definition gaps and the resultant deficits in the current ISO GPS standards.

2.1. TERMINOLOGY

In order to understand the research and purpose of this paper the following important terminologies are explicated with the definitions and the illustrations according to the ISO standards:

- *Datum feature*: real integral feature used for establishing a datum [14].
- *Datum feature indicator*: single features to be used for establishing datum features shall be indicated. The symbol is shown in Fig. 1 [14].

Fig. 1. Datum 1 cm. A box linked to a filled triangle by a leader line [14]

- *Datum*: is a theoretically exact reference to constraint the location and orientation of the tolerance zones. It is defined by a plane, a straight line or a point, or a combination thereof [14].
- *Datum system*: set of two or more datums established in a specific order [14].
- *Orientation only modifier symbol* ><: if the datum is only used to lock the orientation degrees of freedom and not the location. Figure 2 illustrates an ISO example by using the orientation only symbol >< [14].

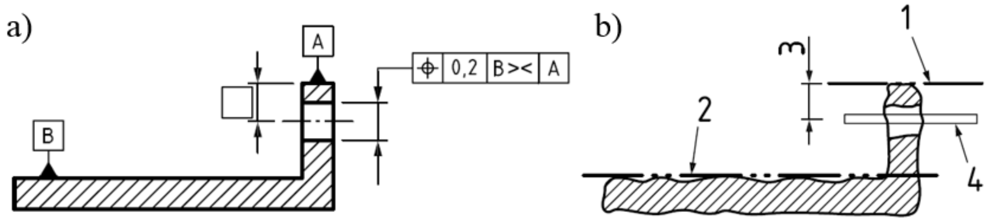

Fig. 2. ISO example of using orientation symbol ><: a) Notation of modifier symbol in technical drawing; b) Meaning. Key 1: datum A, 2: datum B, 3: theoretical exact dimension (TED) of axis to datum A, 4: tolerance zone with orientation constraint from datum B and location constraint from datum A. The tolerance zone can be moved horizontally [14]

- *Intersection planes*: Intersection planes shall be used to identify the orientation of line requirements. Figure 3 shows the graphical language of it [1]. An example of application of the intersection plane indicator is shown in Fig. 4.

Fig. 3. Intersection plane indicator [1]

- *Line profile tolerance*: The toleranced feature can be an integral feature. In Fig. 4a, the primary datum plane A is the rear plane and secondary datum plane B is the bottom plane of this component. In each section, parallel to datum plane A, as specified by the intersection plane indicator, the extracted profile line shall be contained between two equidistant lines enveloping circles of diameter 0.04 mm (see Fig. 4b), the centres of which are situated on a line having the theoretically exact geometrical form with location and orientation respect to datum plane A and B [1, 13].

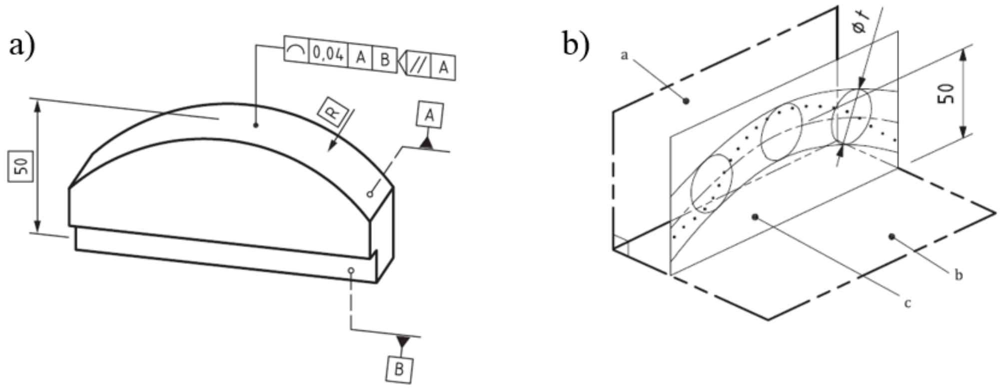

Fig. 4. Line profile tolerance: a) 3D perspective technical drawing; b) Definition of the line profile tolerance zone. Key a: datum A, b: datum B, c: plane parallel to datum A [1]

- *Composite tolerance*: if two or more specifications of the same characteristic are to be indicated (see Fig. 5a), they may be combined as shown in Fig. 5b. It has the same meaning whether it is separate or combined notated [14].

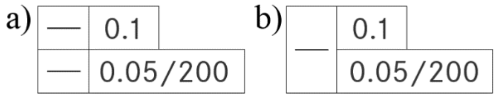

Fig. 5. ISO example of composite tolerance: a) Two separate single straightness tolerance indicators with specifications on a 200 mm restricted length; b) Two combined tolerance indicators. They have the same meaning [14]

2.2. DEFINITION GAPS AND DEFICIT OF ISO

In order to describe specifications of geometrical feature from a component more clearly, additional constraints of location, orientation and form of its tolerance zone can be added. Based on ISO 1101, ISO 1660 and ISO 5459, the additional location, orientation and form of the tolerance zone of an integral intersection line can be specified using the line profile tolerance with orientation only modifier symbol, with or without datums. However, according to ISO, those three additional constraints of the tolerance zones of an integral intersection lines can only be specified separately and unsimultaneously. There are no explicit definitions, examples and notations in ISO, when the additional constraints of location, orientation and form and a combination thereof, can be specified simultaneously. The definitions and the examples from ISO are dispersed, random and illogically established. Therefore there exist definition gaps in the following four combinations of the tolerance zones from line profile composite tolerance simultaneously specifications of the combinations of *location and orientation; location and form; orientation and form; location, orientation and form* of tolerance zone. Hereby the deficit is induced: due to the lack of a logically established and complete systematology of definitions of line profile composite tolerance based on ISO, required definitions of line profile composite tolerance cannot be utilized in practice and cannot be explicitly notated without the possibilities of misunderstanding the technical drawing.

Definition gaps: the following definitions and examples of simultaneously specifications of line profile composite tolerance are not explicitly defined in the current ISO:

- *Location and orientation;*
- *Location and form;*
- *Orientation and form;*
- *Location, orientation and form.*

Deficit: required definitions of line profile composite tolerance of a component cannot be utilized in practice and cannot be explicitly notated in the technical drawing because of the ambiguous definitions.

3. NEW APPROACH

This section offers a logically established and a completely new systematology with hierarchical structure for line profile composite tolerance. Fig. 6 illustrates this new systematology. As mentioned above, in ISO when two or more same tolerance characteristic (e.g. line profile in Fig. 6) are indicated, they can be combined as one tolerance symbol in the tolerance indicator which have the same meaning. This definition is different in comparison with the ASME Y14.5. These shall be paid extra attention while notating the tolerance indicators in technical drawing by using different standards.

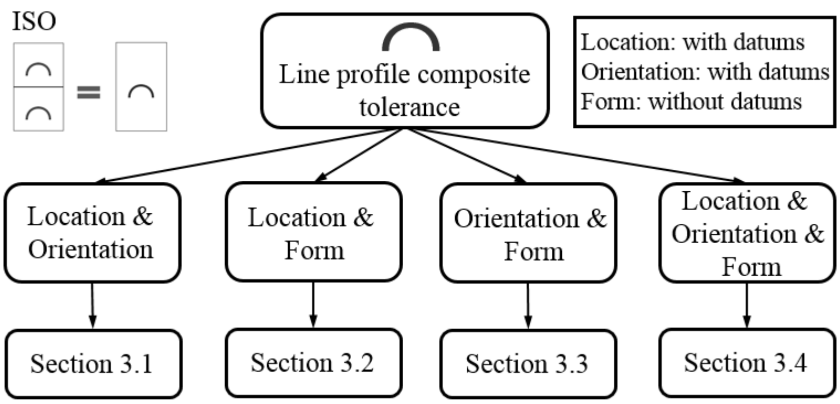

Fig. 6. Logical established and complete new systematology with hierarchical tree structure of line profile composite tolerance

This paper is following the rules of ISO standards. However this is not the focus in this new approach but a framework of conditions. According to the rules and definitions of ISO GPS, the location constraint of tolerance zone shall be applied with datums or datum systems and the orientation constraint as well. But the form constraint of tolerance zone shall be applied without datums. The logical thought model of specification of a geometry feature is, the location of the tolerance zone shall be defined first, then the orientation, the finally the form. The geometrical specification should be kept in this order, it is possible to skip one constraint but the order is not to be reversed. However, this logical thinking is not clearly pursued in the composite tolerance in ISO.

Figure 6 shows the new complete four combinations of additional constraints of tolerance zone which can be specified simultaneously, by using the line profile composite tolerance. These four have covered all the possible combinations of the three additional constraints (location, orientation and form) a specification might contain.

Section 3.1 gives explicit definitions and corresponding examples of additional constraints of *location and orientation* of tolerance zones in line profile composite tolerance while section 3.2 offers the definitions and examples for *location and form*. Section 3.3 gives the definitions and examples for *orientation and form* and finally section 3.4 offers the definitions and examples for *location, orientation and form*.

3.1. LOCATION AND ORIENTATION

Figure 7 illustrates a component similar to the ISO example (Fig. 4). This component has a primary datum plane A which is the front plane, secondary datum plane B is the side plane and tertiary datum plane C is the bottom plane. The datum system A, B and C constrain all the six degrees of freedom of this component. The tolerance feature is the intersection line of the curved surface which is indicated by using the intersection plane A which is parallel to primary datum plane A. The orange colour indicates the location tolerance zone and the green colour indicates the orientation tolerance zone. Based on the logical thinking of specification of a tolerance zone, the location constraint shall be set in the first row, and then the orientation constraint. Figure 7a shows the line profile composite tolerance of constraint of location and orientation tolerance zone. The location tolerance indicator is in the first row which has a complete datum system, therefore its corresponding orange tolerance zone is fixed in the space and cannot be moved. The second row is the orientation tolerance indicator where an orientation only modifier symbol >< is inserted after the secondary datum plane B. It means that the green tolerance zone has only orientation constraint but no location constraint from datum B, meaning the green tolerance zone can be moved horizontally by following the green arrow. After analysing, the notation of tolerance indicator with only datum plane A and C has the same meaning as omitting the datum plane B and its modifier symbol >< (see Fig. 7a). Because without the modifier symbol ><, the intersection line can be constrained by datum A and C with theoretical exact dimensions (TED) and the tolerance feature can only be moved by the unblocked degree of freedom, which is horizontally along datum B. Figure 7b is the similar case as described in Fig. 7a. The only difference is the orientation only modifier symbol >< is placed after tertiary datum C which unblocks the degree of freedom in vertical direction. The green tolerance zone of additional orientation constraint can be only moved by following the green arrow in the vertical direction. Analogous to Fig. 7a the orientation tolerance indicator can be also written with only datum A and B by omitting the datum C with its modifier symbol ><. Figure 7c shows the case which is the combination of Fig. 7a and Fig. 7b that the modifier symbol >< is placed after both datum B and C. These modifier symbols unblock the orientation constraint from datum B and C. Hereby the green tolerance zone can be moved horizontally and vertically. The tolerance indicator can be notated with only datum A by omitting the datums B and C with modifier symbols which keeps the same meaning based on the reason as described above. This is the complete systematology for the case one *location and orientation*: utilization of line profile composite tolerance by simultaneously constraining the *location and orientation* of a tolerance feature. As analysed, the orientation constraint has three cases of movable directions by using the orientation only modifier symbol >< (Fig. 7) which are defined and used in the following sections 3.3 and 3.4 as well. These definitions in this section fill the first definition gap of ISO.

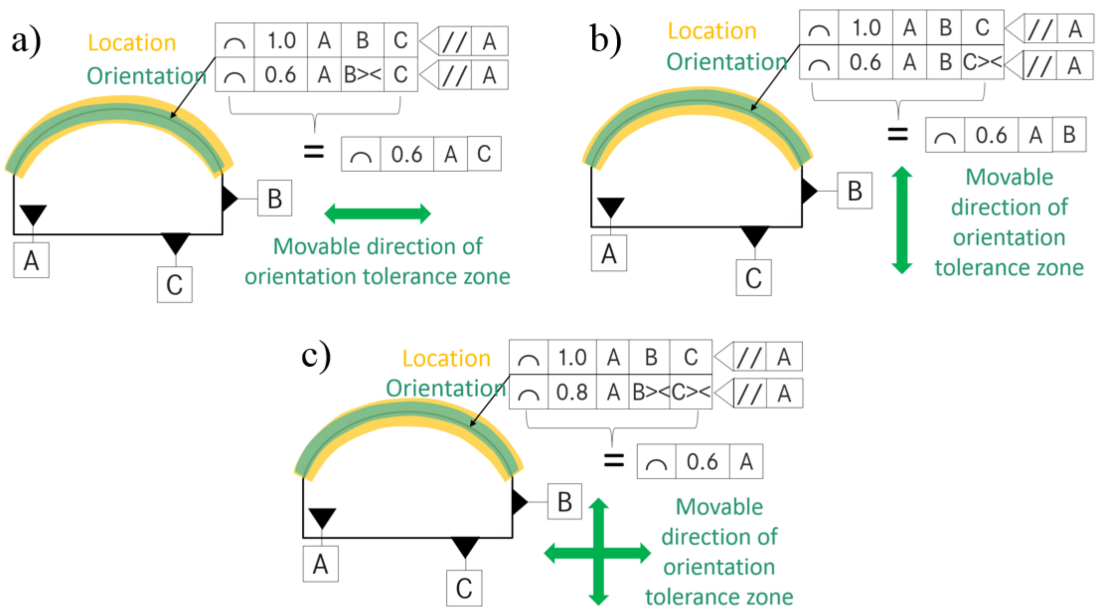

Fig. 7. Additional constraint of location and orientation of tolerance zone of an integral intersection line by using line profile composite tolerance

3.2. LOCATION AND FORM

The second combination of simultaneous specification of tolerance feature by using line profile composite tolerance is *location and form*. Figure 8 illustrates these tolerance zones which are defined by location and form constraint. Figure 8 has the same component with the same datum system and same location constraint as in Fig. 7. The difference is that, in the second row of the composite tolerance indicator is the form constraint of the tolerance zone which is shown in red colour on the intersection line. Based on ISO definitions, the form tolerance of a geometry shall be applied without datums. The tolerance feature (intersection line) can be varied inside of the red arbitrary tolerance zone. The notation rules in ISO that is not explicitly explicated, that the location constraint shall be always notated in the first row and the form in the last row. Because the location of the tolerance zone shall be defined first and then the orientation or the form. As mentioned above, this case is also not explicated defined in ISO GPS standards. This fills the second definition gap of ISO which is described in section 2.2.

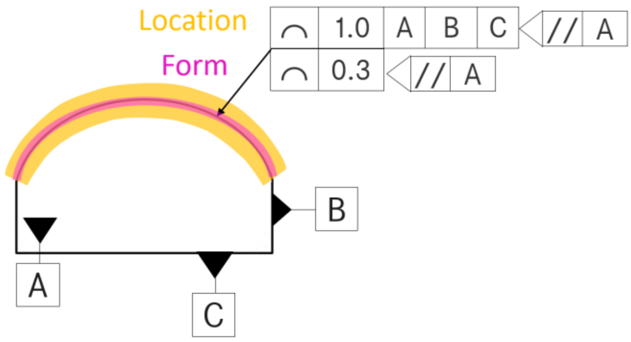

Fig. 8. Additional constraint of location and form of tolerance zone of an integral intersection line by using line profile composite tolerance

3.3. ORIENTATION AND FORM

The third combination of simultaneous specification of tolerance feature (intersection line) by using line profile composite tolerance is *orientation and form*. Fig. 9 illustrates these tolerance zones which are defined by orientation and form constraint. As analysed in section 3.1, there are three cases of orientation constraints i.e. their moveable direction being horizontal, vertical or a combination thereof. Fig. 9a-c show those three cases with different defined movable directions of (green) tolerance zones. The notations of orientation tolerance indicators in Fig. 9 can be replaced as illustrated and explained in Fig. 7 as well. The datum with orientation only modifier symbol >< in the orientation tolerance indicator can be omitted which has the same meaning as before.

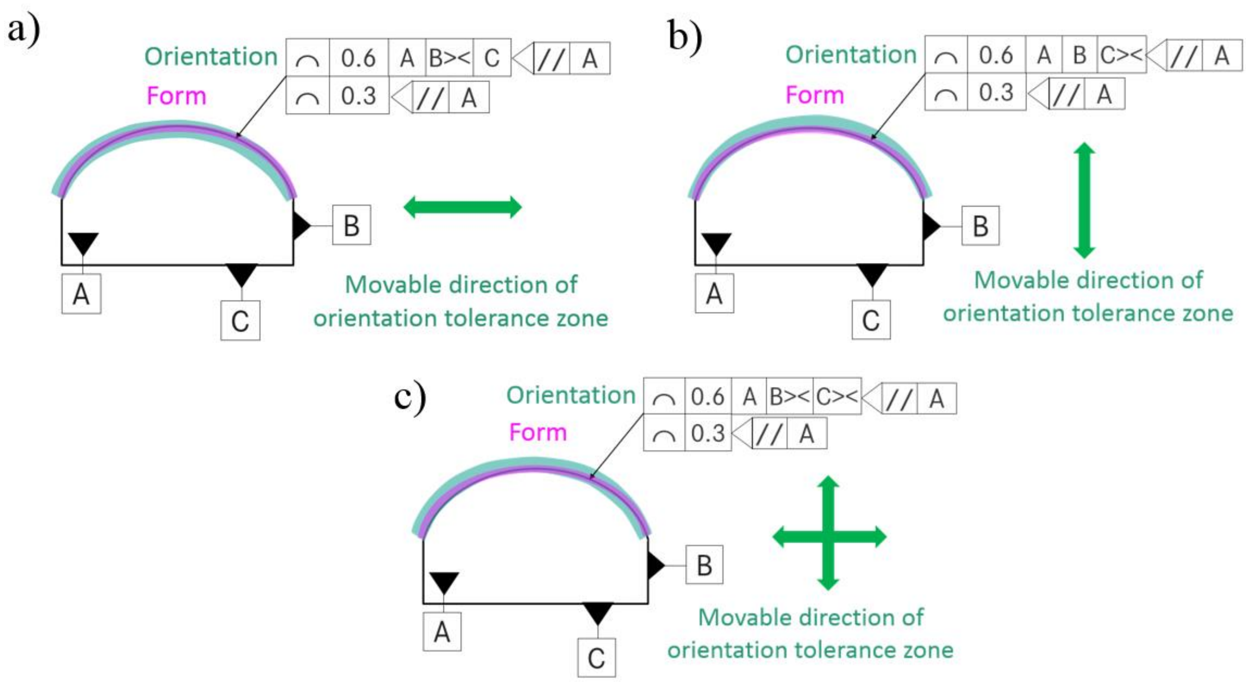

Fig. 9. Additional constraint of orientation and form of tolerance zone of an integral intersection line by using line profile composite tolerance

For example, in Fig. 9a the orientation tolerance indicator with A, B>< and C can be written as A and C where the datum B with the modifier symbol >< is omitted. These two notifications have the same meaning. The form tolerance indicator is notated as in the second row after the orientation indicator in the composite tolerance. Due to the logical thinking the orientation constraint of geometric feature shall be defined before the form constraint. Nevertheless, the tolerance value of form constraint shall be smaller than the tolerance value of orientation constraint. So that the red tolerance zone can be moved within the movable green tolerance zone. These definitions fill the third definition gap of ISO which is listed in section 2.2.

3.4. LOCATION, ORIENTATION AND FORM

The fourth combination of simultaneously specification of tolerance feature by using line profile composite tolerance is *location, orientation and form*. Figure 10 illustrates these location, orientation and form tolerance zones from the same component as the previous sections. There again are three cases where the orientation constraints of the tolerance zones can be moved – horizontally, vertically and a combination thereof. This is already analysed and described in the section 3.1 and 3.3.

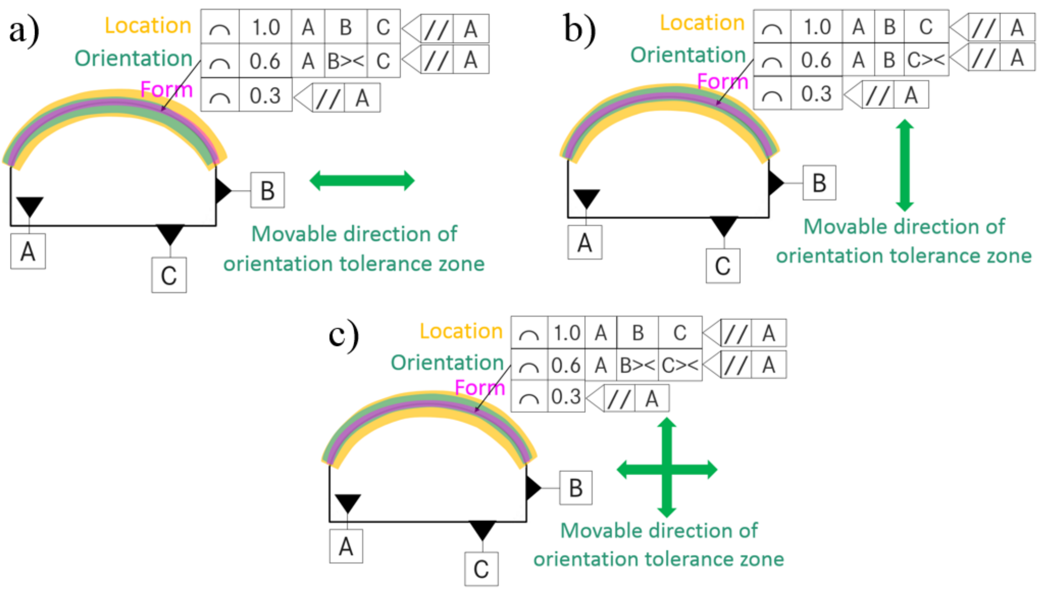

Fig. 10. Additional constraint of location, orientation and form of tolerance zone of an integral intersection line by using line profile composite tolerance

In Fig. 10 the sequences of the tolerance indicators are: firstly location constraint with complete datum system, secondly orientation constraint with datums with the application of orientation only modifier symbol >< after the datums and thirdly is the form constraint without datums. The tolerance values of location (1.0 mm), orientation (0.6 mm) and form (0.3 mm) are decreased so that the red form tolerance zone can be moved inside of the movable green orientation tolerance zone, while the green orientation tolerance zone can be moved within the orange fixed location tolerance zone. This sequence and the definitions and the corresponding examples of simultaneous specifications of line profile composite tolerance and other composite tolerance are not explicitly defined in the ISO GPS standards. These definitions which are defined in this new approach fill the definition gaps, eliminate the ambiguity and enhance the usability of ISO GPS standards.

4. CONCLUSION

This paper presented a novel approach for definitions of all combination possibilities of additional constraints of location, orientation and form tolerance zones for a geometric feature under application of line profile composite tolerance. Moreover, a new holistic and function-oriented systematology with hierarchical structure for the complete definitions of composite tolerance was developed as well. The explicitly defined new definitions and systematology fill the definition gaps and eliminate the corresponding deficit imposed by the current ISO GPS standards. The ISO definitions of line profile composite tolerance were also completed and enhanced. Future work involves applying this approach to other tolerance characteristics.

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