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Product Value Enhancement by Manufacturing Process Optimization and Tolerances Standardization

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Abstract

In any technical drawing, it is important to use the precise tolerance value on dimensions with special attention on critical and major dimensions. While deciding the tolerance on any particular dimension, the designer uses his skills along with the manufacturing/serviceability/assembly feasibility, criticality to vehicle performance and prior experience. In the proposed paper, the addition of all such tolerances with standard and manufactural values is done in tabular format as per product manufacturing processes like steel stamping, welding, machining, casting and forging components in different combinations for a ready reference to designer and manufacturer. Integration of right manufacturing process during design stage itself in 3D CAD (Computer Aided Design) environment will eliminate wrong part development due to non-standard tolerances and manufacturing process. This will reduce the time and skills required in deciding the concerned dimensions and tolerances with improved product quality and assistance to the development and quality assurance (QA) team in the earliest stages of product and process development.

Keywords

Tolerance, Quality assurance, Product quality, Design stage, Product quality

Introduction

World class quality (WCQ) aims to not "Accept, Create, Release" a defect and "Engineering quality and quality in everything we do". Inline with this objective, it is important to precisely mention the required dimensions and tolerances in technical drawings. In the classical approach, the designer mentions dimensions and decides the tolerance based on stack-up analysis, criticality, manufacturing and assembly feasibility, prior experience, Incidence per thousand vehicle data, required product life, etc.

Below is the present scenario of the use of general tolerance table in drawings:

- General tolerance table of "Linear and angular dimensions and surface roughness" is present in all drawings irrespective of any component/assembly. When this table is not applicable for the concerned component/assembly, the designer usually cross marks this table.
- In the case of casting and moulded component drawings, the general tolerance table is present but standard recommended grades for machining general tolerance table is missing.
- For rubber parts, cut length and cross-sectional tolerance tables are not available which are required for brake and steering group (rubber/nylon) pipelines.

- During assembly, tolerance stack-up is required for deciding the worst case of assembled condition w.r.t. the standard tolerance table given in the component level drawing.
- In the case of BIW components and assemblies, their drawings have only machining tolerances and notes for welding and steel stamping manufacturing process.

Drawing is one of the ways to convey design intent to subsequent agencies that are involved in part development like planning, manufacturing, inspection, assembly, and service. Based on virtual review feedback, designers create detailed drawings of components and assemblies for development. It is done mainly with the manufacturing intent.

The general tolerance should be published on the drawing design in reference to TS/IS standards. The value of nominal tolerances matches grades of workshop precision, the defined tolerance grade to be selected and published on the drawing/design as per the requirements for the product design and development [1].

In this paper, all such tolerances will be provided as a ready reference in tabular format so that the designer can select/call the appropriate/applicable general tolerance tables and notes in drawing format without much effort and time consumption. The general tolerance matrix table has been created based on the product manufacturing processes like steel stamping, weldment structure, machined, casted, and forged components in different combinations. This table is based on the relevant national/international standards, manufacturing, development, and assembly feasibility along with the cost impact. It will enhance the part quality and reduce the development time and cost. This work instruction will bring more clarity in the implementation of standard drawing format and general manufacturing tolerances for preparing the drawings.

The salient features of proposed work are:

- Standard drawing format and filling information
- General tolerance as per manufacturing process
- CAD BOM and Engineering BOM Management
- Robustness of checklist for design modification and release
- Standards revision

The general tolerance should be published on the drawing/design by as per the TS/IS standards. The value of nominal tolerances matches the grades of workshop precision, the appropriate tolerance class being selected and published on the drawing/design according to the requirement for the product design and development. Currently, general tolerance tables and notes are not present in drawing format as per the product manufacturing process requirements.

As per figure 1, the product is categorized based on material and its manufacturing process. The respective general tolerance tables will be added in drawing format while creating the drawing in CAD tools e.g., Creo, Catia, etc. as per figure 2.

Shown in figure 3 is a brief part and assemly type drawing classification based on specific material and its manufacturing process.

Literature Review

For the proposed practice, references are taken from various engineering journals and R&D stakeholders (QA,

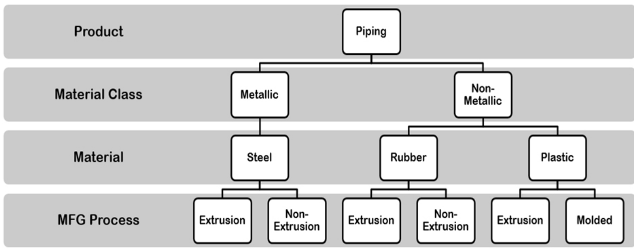

Figure 1: Product manufacturing process.

Tolerance on outside dimensions of surface-ground extrusions		
Nominal Dim's above	Nominal Dim's up to & including	Class EG2
0	10	±0.25
10	16	±0.35
16	25	±0.4
25	40	±0.5
40	63	±0.7
63	100	±0.8
100	160	±1.0

Tolerances on cross-sectional dim's of unsupported extrusions		
Nominal Dim's above	Nominal Dim's up to & including	Class E3
0	1.5	±0.40
1.5	2.5	±0.5
2.5	4	±0.7
4	6.3	±0.8
6.3	10	±1.0
10	16	±1.3
16	25	±1.6
25	40	±2.0
40	63	±2.5
63	100	±3.2

SURFACE ROUGHNESS SYMBOLS / VALUES IN µm Ra								
Symbol	N12	N11	N9	N7	N6	N3	N6 GRD	N6 HRD & GRD
Value	50	25	6.3	1.6	0.8	0.1	0.8	0.8
FOR OTHER ROUGHNESS SYMBOLS & VALUES, SEE IS 10719								

Tolerences on cut length of extrusions		
Nominal length above	Nominal length up to & including	Class L3
0	40	±1.6
40	63	±2.0
63	100	±2.5
100	160	±3.2
160	250	±4.0
250	400	±5.0
400	630	±6.3
630	1000	±10
1000	1600	±12.5
1600	2500	±16
2500	4000	±20

Unless otherwise stated, general tol. for rubber part as per TS12120

Tolerances on thickness of cut sections of extrusions		
Nominal Thickness above	Nominal Thickness up to & including	Class EC3
0.63	1	±2.0
1	1.6	±2.5
1.6	2.5	±3.5
2.5	4	±0.4
4	6.3	±0.5
6.3	10	±0.7
10	16	±0.8
16	25	±1.0

Tolerance on extrusions			
Nominal Dim's above	Nominal Dim's up to & including	Internal dim's (mandrel-supported) Class EN3	Wall thickness (Surface ground) Class EW2
0	4	±0.35	±0.20
4	6.3	±0.4	±0.20
6.3	10	±0.5	±0.25
10	16	±0.7	±0.35
16	25	±0.8	±0.40
25	40	±1.0	-
40	63	±1.3	-
63	100	±1.6	-
100	160	±2.0	-

Figure 2: General Tolerance tables in drawing format as per part manufacturing process (for extrusion rubber product).

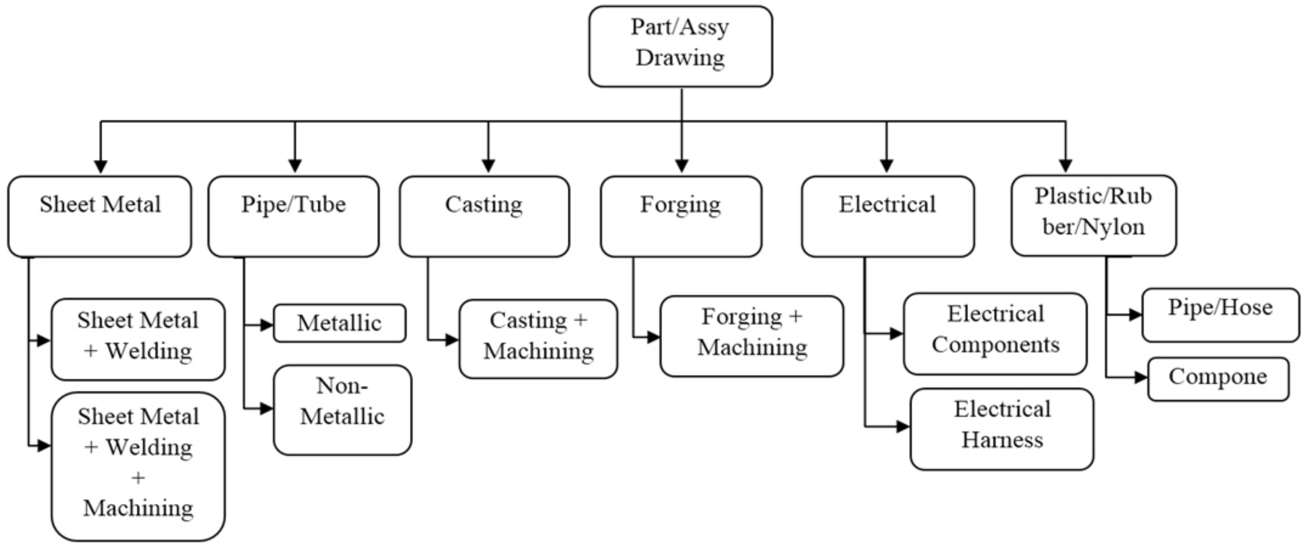

Figure 3: Types of part and assembly drawing.

Vendor Development, and Assembly Line Departments) for understanding their issues while developing and inspecting the components. The effect of manufacturing tolerances for design variables on the solution to an optimization problem is studied for two formulations of the tolerance problem [2]. Simple analysis and early-stage design methods can help in better understanding one of the potential reasons of variance in manufacturing tolerances, namely the variation inherent in manufacturing, assembly, and use processes [3]. The causes of engineering change propagation during the development and production phases of the product lifecycle using a statistical method applied for determining the accurate applicable tolerances in engineering problems [4]. The demand for "The better-quality product with shorter lead time and lower life cycle cost with concurrent engineering (CE) also require tolerances optimization for achieving the WCQ milestones [5].

Firstly, a robust and value-driven drawing and design framework is proposed for product and process engineering innovation for sustainability and provides conceptual design, production, supply chains, partnerships, and distribution channels. Then, the tolerance value based on the applicable table is applied with computer-aided product development proposed as a useful tool to support sustainable value-oriented product and process engineering [6]. The current engineering process in the automotive industry is chiefly part oriented. What counts most, however, is the optimization of complete assemblies whereas, Design for Assembly (DFA) subordinates' development to the optimization of the production process [7]. The concept of Digital Validation Planning as presented here is based on a process paralleling that of digital planning enabling the designer and manufacturing team to decide the most suitable and achievable tolerance throughout the part drawing [8]. Product Lifecycle Management is the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of [9]. Design activities with detailed drawing outline the requisite technical documentation (technical drawings, circuit diagrams, CAD models) which is required to produce successful products [10]. Both the length deviations and the angle deviations are uniformly represented by accurate dimensional tolerance with stack-up functions relating the assembly functional requirements to the manufacturing variations [11]. The probabilistic approach makes it possible to perform trade-off between performance and tolerance rather than the worst-case analysis as it is commonly practiced [12].

Based on the literature review, we found out that the tolerance tables and standard notes availability in drawings as per components/assembly manufacturing processes was missing in most of the Original Equipment Manufacturers (OEMs). Ensuring its availability can be directly helpful to the part developer, during the assembly process and at the time of quality check.

Methodology

In the current component/assembly drawing creation process in Creo 7.0, the proposed concept of applicable tolerance table addition has been implemented. The tolerance tables are based on the component/assembly parameters like material, material thickness, material grade, coating, supply condition, manufacturing process and feasibility, surface protection, weight requirements, etc.

Part/assembly manufacturing process tolerances are categorized in different classes/accuracy grades from different standards like IS, JIS, SAE, and TS for ensuring WCQ products. In case of tighter tolerances, more manufacturing cost is involved. Selecting a class which optimizes both seemed to be a tricky task. Technical journals were referred and consultation with Advance Quality team, Suppliers was done to achieve this balance. For example: a geometry feature having a 41 mm length could be manufactured to a high level of conformance in a workshop with "precision". Defining a tolerance of ±1 mm would be of no use in this workshop, as the nominal tolerance values of ±0.3 mm would be sufficient to attain quality product.

However, if for any reason, a geometric feature needs a tighter tolerance value than the nominal tolerance then that geometric feature should have the tighter tolerance published beside the dimension defining its size. This type of tolerance falls outside the purview of nominal tolerances.

As per figure 4, the most suitable tolerance table is created automatically in the proposed practice. This helps the designer in selecting an appropriate general tolerance table as per product manufacturing process. Thus, it helps the development and QA teams in part manufacturing and inspection by providing ready reference avoiding the requirement of additional relevant standards at supplier end and quality inspection cell. It also helps the designer in selecting the appropriate tolerances based on the recommendation from this tolerance table.

The drawing creation process has been optimized in such a manner that the designer/draftsman only has to take care about the part and material, CAD software will automatically take care about the manufacturing process based on the vendor and supplier of the concerned plant location and insert the applicable tolerance table into the drawing format, enabling the designer/draughtsman, manufacturing people through proceed the development work without referring any other standards.

Material grade is selected as per part requirement and general tolerance is linked with the part manufacturing process as shown in table 1. The category of the materials and their manufacturing processes can be added as per the OEM's requirements.

Example:

Material = Steel

Material manufacturing process = Hot rolled

Material Grade & Supply Condition = Fe410WA, SS440

Start drawing template will be created by modifying drawing creation process in conventional method with the help of Creo tool kit. We have added all the proposed inputs (attribute/manufacturing process) in the start drawing template. While creating new drawings, the designers are recommended to use a start drawing template for getting an appropriate general tolerance table as per selected material and manufacturing process.

Table 1: Material manufacturing process.

Sr. No.	Material	Manufacturing process
1	Rubber	Moulding/Extrusion/Calendaring
2	Plastic	Injection moulding
3	Aluminum	Light metal alloy gravity die-castings/Light metal alloy pressure die-castings
4	Aluminum Alloy	Light metal alloy pressure die-castings
5	Steel Stamping	Flat steel hot & Cold stamping/ Shearing & Bending
6	Steel	Stamping forming excluding radii of curvature/Stamping forming including radii of curvature/Drop & press forging/Forging hot rolled black bars & billets/Flame or induction hardening

Results

To validate the proposed practice, a comparative study was carried out between the drawings prepared using the conventional method and the proposed part/assembly drawing template and other one was carried out between drawings referred for part quality check using both the methods to calculate the time and cost saved. The conventional method of product design and development activities break-up for selection/verification of tolerance is given in table 2.

Activities mapped in table 2 need to be repeated at the time of drafting of drawing, DFA/DFM/DFMEA signoff process, part production/development and part inspection and thus the time required for performing above activities during different stages of product development is repeated multiple times as shown in table 3.

In table 3, we have conducted time study for relevant tolerance selection for the activities performed during different stages of product development using conventional method and found that an average 30 Min and 44 Sec is spent for referring the tolerance tables for single part. The time taken may increase depending on the lack of awareness of standards to the user and the efficiency of the processes in the OEMs. A cost benefit analysis over conventional method was done and it was found that 30 Min and 44 Sec is the total time saving per iteration through various agencies like Design, Manufacturing, Assembly line/Production and Central Quality as shown in table 4.

Thus, it can be concluded that a significant amount of

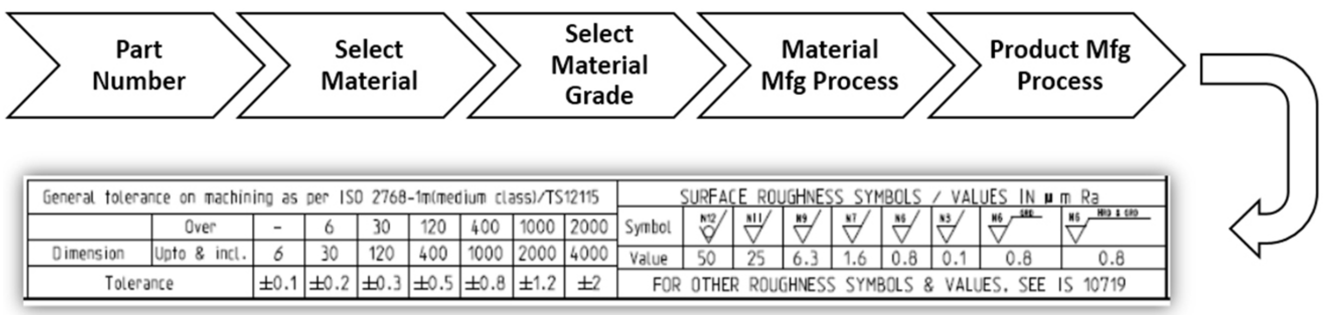

Figure 4: General Tolerance tables in drawing format as per part manufacturing process.

Table 2: Time study for tolerance selection.

Sr. No.	Activities for each STD	Occurrence	Time required for doing activity (Sec)	Total time (Sec)	Remarks
1	Browse the link of standard	2	18	36	Each time when standard is to be referred
2	Open drawing standards	2	40	80	- Do -
3	Search for relevant tolerance table	3	10	30	Repetitive for different type of dimensions
4	Select tolerance for controlled dimensions	3	25	75	Repetitive for each dimension
5	Verify tolerance for open/ uncontrolled dimensions	12	20	240	- Do -
	Average time for one drawing			**461**	

Table 3: Time study for tolerance selection.

Sr. No.	Activities for each STD	Reference to tolerance table required	Time required for repeated activities during different stages (Sec)
1	Drafting of drawing	Yes	461
2	Study of the drawing for DFA/DFM/DFMEA	Yes	461
3	Part production/ development	Yes	461
4	Quality inspection at the time of part development	Yes	461
	Average time for one drawing		**1844**

cost and time can be saved using the proposed methodology. This will surely result in improved productivity as well as better product quality with optimized efforts.

Discussion

While implementing the proposed practice, a new drawing template is a key challenge requiring skilled developer with Creo7.0 tool kit license. It may happen that this work has to be outsourced, which may result in the loss of confidential data of the company and has to be protected by any means.

Table 4: Cost benefit analysis.

Sr. No.	Category	Details	Amount
1	Time	Time saving in one drawing	30 Min and 44 Sec
2	Drawing	Average drawings created by designer in a day*	2 Nos.
3	Manpower	Total man hours saving in a day/designer	2 x 30/60 = 1 hr
4	Savings	Savings per designer per day	1 x 1000/8 = Rs. 125
	Benefit (Total Savings/per designer/month)		**Rs. 125 x 26 = Rs. 3250**

*Rs. 1000 is taken as average per day cost of a designer.

Note: *The total savings per month will vary with the number of designers available in the OEMs. For example, Tata Motors Engineering Research Centre (ERC) has a total of around 3500 designers. Hence, the savings for Tata Motors after implementing this proposal will be Rs. 3250 x 3500 ~* ***Rs. 1.1 Cr/ month*** *(the study was conducted at ERC, Tata Motors and this process has also been implemented here).*

**A survey was conducted in our organization to find out the average number of drawings drafted by a design engineer, and it was found out that one engineer drafts around 2 new drawings per day. We have not considered the drawings which are taken up for modification/ revision as tolerances, standards and notes are already covered in those drawings.*

Secondly, there are chances that the referred manufacturing tolerance table may get revised. In that case, the solution developer team can forget to update the drawing template which will result in mismatch between the proposed and revised standards.

Other Recommendations

While creating the product drawing, we should focus on manufacturing and fitment aspects as well as facilitation of inspection. In manufacturing aspects, material supply condition/grades, manufacturing activities (dimensions, surface finish, keynotes, critical symbols, locating points, etc.), joining operations (welding, riveting, press fitting, fastenings, lose fit, paste, etc.) to be defined/specified on drawing. In fitment aspects, the dimensions critical to fitment/mating part must be given in drawing and well controlled by tolerance. In facilitation of inspection, the dimensions and tolerance in the drawing must be given with reference point/ datum/ surface/ imaginary axis at the critical areas. If the dimensions are not provided from reference datum, desired dimensional requirements cannot be ensured. Reference datum is defined majorly with focus on fitment and part functionalities requirements. For defining any object position in co-ordinate space, its dimensions from three datum planes (X, Y, Z) must be defined, the geometric tolerance for the object must be defined with respect to these datum planes and while applying geometric tolerance on features, one should try to use minimum datum planes to define all geometric tolerances,

Secondly, In CAD DMU (Digital Mock-up), for forging and casting parts, draft angles are not shown CAD model and due to this, most of the time, the designers are not aware and clear the DMU without checking proper clearances.

Thirdly, geometrical tolerance cannot be left as open tolerance because geometrical tolerances are product functional requirements and sometimes the same is related to the other geometrical tolerances also. For example, if we provide flatness as a 0.5 mm then we have to maintain perpendicularity w.r.t. flatness which will be more than 0.5 mm or 1.0 mm.

Conclusions

This research paper aims at the introduction of various tolerance considerations and addition of tables into the current part/assembly drawing template in order to enable the designer to select the accurate tolerance with ready reference. The following conclusions are drawn.

1. The drawing drafting saves time by preventing elaborate tolerance calculation as it suffices to know that the feature allows a tolerance greater than or equal to the nominal tolerance.
2. Supply chain can discuss orders more easily since the "precision" is known before the MOU is placed; this also prevents concern on logistics between the customer and supplier, since in all respect the drawing/design is complete.
3. Facilitating part manufacturing just in time and ensure its adherence with the QA guidelines.
4. Drawing features which have individually indicated geometrical tolerances including major and critical (full and half-moon symbol) will for the most part be those controlling features for which the function requires relatively small tolerances, and which therefore may cause special effort in the production.
5. Useful for planning and will allow quality function in their analysis of verification.

This will also optimize the product cost by availing easily available open dimension tolerances and will consequently reduce the project timeline as well as the cost involved. This is essential for the automotive organizations moving towards WCQ achievement and better product delivery with overall time reduction from drawing board to market.

Approach to create drawing through customize CAD software, the drawing template is selected based on the part type and material manufacturing process to decide the applicable tolerances suitable for product development to assist the manufacturing agencies in design for manufacturing (DFM) and DFA signoff and quality inspection team for facilitating the quality assurance. The designer/draughtsman will complete the drawing, go for release share to manufacturing department for further processing. No need to share any additional standard for reference. Since all the required information will be available in drawing itself.

Acknowledgements

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Conflict of Interest

None.

References

1. Hopp TH. 1993. The language of tolerances. *Computer* 14(5): 1-17.
2. Balling RJ, Free JC, Parkinson AR. 1986. Consideration of worst-case manufacturing tolerances in design optimization. *J Mech Trans and Automation* 108(4): 438-441. https://doi.org/10.1115/1.3258751
3. Eifler T, Howard TJ. 2018. The importance of robust design methodology: case study of the infamous GM ignition switch recall. *Res Eng Design* 29: 39-53. https://doi.org/10.1007/s00163-017-0251-x
4. Eisa H, Garstenauer A, Blackburn T. 2018. Causes of engineering change propagation: an analysis during product lifecycle. *Eng Manag J* 30(1): 3-13. https://doi.org/10.1080/10429247.2017.1394418
5. In Lienig J, Bruemmer H. 2017. Design Process and Its Fundamentals. In Fundamentals of Electronic Systems Design. Springer, Cham, pp 5-30.
6. Ramnath BV, Elanchezhian C, Naveen E, Rekha G, Vidhyarajan M, et al. 2018. Implementation of concurrent redesign & manufacture procedure for an automotive component. *Mater Today Proc* 5(1): 1418-1424. https://doi.org/10.1016/j.matpr.2017.11.228
7. In Stark J (ed) Product lifecycle management (PLM). In Product Lifecycle Management (Volume 1) 21st Century Paradigm for Product Realisation. Springer International Publishing, pp 1-32.
8. Tao J, Yu S. 2018. Product Life Cycle Design for Sustainable Value Creation. In Zhang Y, Gregory M (eds) Value Creation Through Engineering Excellence: Building Global Network Capabilities. Palgrave Macmillan Cham, pp 297-326.
9. Vielhaber M, Burr H, Deubel T, Weber C, Haasis S. 2004. Assembly-oriented design in automotive engineering. In DS 32: *Proceedings of DESIGN 2004, the 8th International Design Conference*, Croatia, pp 539-546.
10. Wöhlke G, Schiller E. 2005. Digital planning validation in automotive industry. *Comput Ind* 56(4): 393-405. https://doi.org/10.1016/j.compind.2005.01.010
11. Yu J, Zhao Y, Wang H, Lai X. 2018. Tolerance analysis of mechanical assemblies based on the product of exponentials formula. *Proc Inst Mech Eng B J Eng Manuf* 232(14): 2616-2626. https://doi.org/10.1177/0954405417703425
12. Lee W J, Woo TC. 1990. Tolerances: their analysis and synthesis. *J Eng Ind* 112(2): 113-121. https://doi.org/10.1115/1.2899553