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Functional tolerancing: Virtual material condition on complex junctions

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ABSTRACT

In industry, functional tolerancing of mechanisms is today more and more based on ISO GPS (Geometrical Product Specification) and ASME standards. In this context, the CLIC method (French acronym for "Cotation en Localisation avec Influence des Contacts") has been developed in our laboratory since 1998. The method describes the complete process involved in functional tolerancing. The three dimensional calculation of the result of tolerance chain is formulated functions of tolerances and offsets of surfaces, based on transfer by tolerance zone or by virtual boundary. However, the current standards are incomplete to specify complex junctions, for example to respect a minimum clearance. The paper outlines that the independence principle does not permit to limit the orientation inside location zone in particular case with floating datum reference frame. Then, two main contributions are developed, the extension of material conditions on complex surfaces and the definition of a new association criterion in order to specify hybrid prismatic surfaces with a surface contact zone and a zone with clearance. In this aim, the paper advises six propositions as possible extension of standards of tolerancing.

1. Functional tolerancing and dimensioning

1.1. Scientific context

The CLIC method [1] enables to elaborate a functional tolerancing based on notion of virtual boundary and a three dimensional tolerance analysis. Junctions between parts are described according to priority order with primary, secondary and tertiary links.

The objective of this work is to extend the CLIC method to complex links composed of prismatic surfaces or free surfaces. It is necessary to propose a functional tolerancing for these junctions in order to respect geometric requirements and to generate transfer equations. For that, the calculation model should be consistent with respect for the definition of the specification.

Several extensions of ISO standards will be proposed to generalize the concept of virtual condition to complex surfaces. Nowadays, these proposed specifications are out of ISO or ASME current standards [2].

The second section reminds the tolerancing method for transfer on simple mechanisms, in order to explain the necessity to add an orientation specification to a position specification and the interest of virtual condition specification. One difficulty is underlined for the mobility of the datum reference frame with least material virtual boundary.

The third section introduces the need of virtual condition on complex surface and proposes a new specification which respects the independence rule.

Finally, the fourth section analyzes a link denoted "hybrid" constituted of both contact feature and fitting feature for the same geometric entity. Therefore, it is necessary to use specific writing with a new association criterion.

1.2. Result of a tolerance chain

Generally, a junction between two parts is realized by a primary link, a secondary link and eventually a tertiary link [3]. These links can be classified in different type, by using the concept of set of surfaces and TTRS for Technologically and Topologically Related Surfaces developed by A. Clément [4]: planar surface, cylindrical surface, prismatic surface, surface of revolution, spherical surface and complex surface. Each link is formed by one or several surfaces.

In the industries, the most efficient approach is the tolerance analysis by computer aided-tolerancing software 3DCS® (Dimensional Control Systems), CETOL® (Sigmetrix), VSA® andeM-Tol-MAte® (Siemens PLM) which are often based on Monte Carlo methods. For that, the designer has to choose geometric specifications applied on parts [6]. The software simulates then a population of components with defects generated by Monte Carlo simulation and assemblies virtually parts. The desired characteristic is measured on final assemblies, which allows estimating the result of the tolerance chain in worst case or in statistic. The quality of these

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results depends on chosen specification, junction model and different adjustments for random number generator.

Scientific approaches can be classified into four categories.

An easy solution is to model the junction by punctual contacts which form isostatic links (MECAmaster) [7]. The deviation on each vertex represents the clearance effect and location deviation of the bearing surface. So in links with clearance, the designer has to determine contact points between parts function of the studied requirement. The model depends thus on the studied requirement and on chosen analysis direction.

Several authors consider that all surfaces of link have orientation and location defects. Real surfaces are modeled by substituted ideal surfaces (form defect is not taken into account) which have an orientation and location deviation relative to the nominal surface defined in CAD model [8,9]. For example, the deviation of a plane is expressed function of three parameters, two rotations and one translation. A hexagonal link with six planes imposes consequently 18 parameters. The mobility of the part is modeled by the six degrees of freedom, which enable to calculate the displacement of ending surface vertexes.

Constrains of mating impose constrains between these parameters. The derived relationships show influent deviations relative to the requirement. The designer must then choose specification and tolerance values which permit to control these influence deviations, which allows calculating searched displacements.

Systems of equations can be very complex. M. Giordano [10] and D. Tessandier [11] present results with domains and polytopes, but this can be complex with a great number of parameters.

The third approach consists in simulating local defects of surfaces. J.K. Davidson depicts the surface in the form of T-Map® [12]. Samper [13] suggests a modal model which permits to parameterize the form defects. In both cases, defects must be generated in order to determine contact points between the pair of surfaces.

The fourth approach is based on boundary conditions defined in the standard ISO 2692 [14] and ASME 2009 [15]. The major interest is to consider the assembly with perfect form part, at maximum material to check if the assembly is possible or at least material to determine the maximum displacement of the ending surface. The fundamental hypothesis supposes that the displacement will be greater when links are at least material conditions. This approach is very efficient to compute the greatest displacement in worst case but does not allow good statistic evaluation.

The CLIC method refers to this last approach [1]. The tolerancing proceeds in two steps. The tolerancing of junction surfaces enables to create the main datum reference frame on positioning surfaces and an auxiliary datum reference frame on support surfaces. Form specifications assure the quality of the contact. Specifications at maximum material condition guarantee the assembly. In the second step, positioning surfaces are positioned each relative to the others, by locating each surface of the auxiliary datum reference frame with regard to the main datum reference frame, this using the concept of least material condition for fitting features of the junction and finally by locating the ending surface relative to the main datum reference frame of the ending part.

In this paper, the approach will be illustrated by elementary mechanisms constituted of two parts noted housing and body. The considered requirement on this mechanism will be a location of an ending surface belonging to the body relative to a datum reference frame of the housing. If there is clearance, the requirement must be respected for all positions of the body obtained by the mobility allowed by the clearance.

2. Basic transfers

2.1. Transfer with a planar link

Fig. 1a illustrates a basic mechanism composed of a body and a housing. Plane *A* of the body is in contact with plane *H* of the housing. A location requirement (R1) imposes to control the maximum height at vertex *F*. For that, the analysis line method [1] determines the displacement of the vertex F_1 and F_2 located at extremities of the hole axis in analysis direction **f**.

The distance between *F* and contact face is *L*. The contact surface *H* of the housing is specified by a location (S1) and an orientation (S2) Fig. 1b and c. The real surface has to remain inside these two tolerance zones. The datum plane *A* of the body bears down the real plane of the housing Fig. 1d.

The contact hypothesis considers that the datum plane *A* of the body remain in the orientation and location tolerance zones of *H* surface of the housing. Measurements done by Radouani [16] show that this hypothesis is not perfectly respected and there is an overtaking and a possible interference which depends on the sum

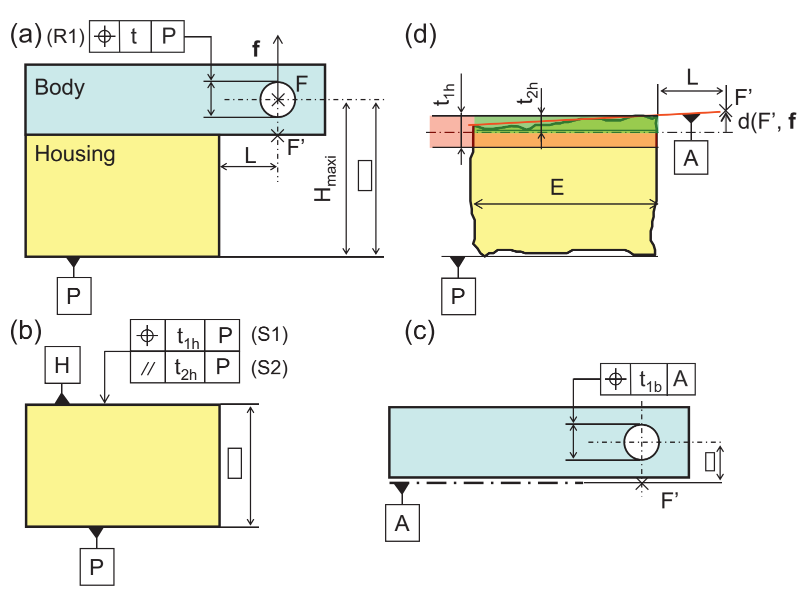

Fig. 1. Basic tolerance chain with contact surfaces.