IOP Conference Series: Materials Science and Engineering

Automated assessment of the low-rigid composite parts influence on the product assemblability in the GePARD system

To cite this article: D S Leonovich *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **760** 012038

IOP Conf. Series: Materials Science and Engineering **760** (2020) 012038 doi:10.1088/1757-899X/760/1/012038

Automated assessment of the low-rigid composite parts influence on the product assemblability in the GePARD system

D S Leonovich[1], D A Zhuravlev[1], Yu I Karlina[1], A S Govorkov[1], A I Karlina[1]

[1]Irkutsk National Research Technical University, 83 Lermontov Street, Irkutsk, 664074, Russia

E-mail: karlinat@mail.ru

Abstract. Composite components tend to have higher deviations from the nominal dimension in conjunction with metal components. Composites production processes simulation methods have already been developed before long time ago. This article presents the possibility of integrating the technique of non-rigid dimensional chains, taking into account the elastic properties of composite materials to assess the products assemblage with machinery parts from composite materials, on the basis of three-dimensional GePARD system. The fundamental points of the dimensional chain calculating method with non-rigid parts, as well as methods of assessing the stiffness for some types of composite materials, which take into account some peculiarities of its structure, are also examined. The assemblability of an assembly unit is represented by the parameter of the functional assembly requirement depending on the critical accuracy characteristics.

1. Introduction

Geometry and design of any industrial product must match characteristics that were laid by a design-engineer in a part construction, i.e. must perform all the dimensional parameters and provide expected functions. In the ideal model, a competently designed and manufactured product or part of it does not need to be modified at the assembly level and operation stage. In modern production, these aspects are solved through the use of automation of the computer-aided design and life cycle processes modeling, which require more detailed information about nominal geometry with permissible deviations in the electronic layout of the product. It should be noted that these deviations are a kind of important macro-information that forms the electronic model of the product.

Advanced high-tech products of our time have a different number of nodes containing low-rigid parts, which will be discussed in this article. Mechanical engineering technology in the field of interchangeability methods in machining can't be used in an assembly process of this products type, otherwise there is no guarantee of required quality with acceptable costs parts reception.

The theoretical basis of the products assembly processes began to form a scientific concept of engineering technology emergence and in practice there are various options for assessing and calculation of the final product assembly, which have their effectiveness and their advantages/disadvantages [1-4]. These provisions are based on the following fundamental points introduced by B. S. Balakshin: method of achieving the accuracy of a closing link, the dimensional chains theory and the basing theory [4]. One of the most significant methods is the method of dimensional analysis, set out in the Russian Federation

IOP Conf. Series: Materials Science and Engineering **760** (2020) 012038 doi:10.1088/1757-899X/760/1/012038

in the form of state standard GOST 16319-80 and in the form of guidelines RD 50-635-87. Dimensional analysis of engineering products provides an opportunity to calculate optimal geometric parameters-tolerances accuracy. This factor should be considered as factor of the final product efficiency and quality determination. The dimensional chains analysis can be both design and technological, therefore, these process of design and technological activity cycle form tasks that demands the use of automated facilities.

2. Chapter 1: Dimensional analysis of assemblies with non-rigid components

The assembly stage is a labor-intensive final technological process, which particularly affects the final characteristics, cost and competitiveness of any machine-building product, including the problems of the manufactured products quality improvement, reducing production and reducing the preparation time for serial production costs.

The assembly with low-rigid composite materials parts can be considered as a dimensional chain designing process which represents the mathematical model of the real final product, where inaccuracies of the parts are summed according to certain laws. According to the classical dimensional chain theory, dimensional error does not take into account parts rigidity, which even with correctly performed dimensional calculations in some cases does not guarantee quality of the assembly. In this regard, the accuracy, which is inherent in the design documentation and is achieved in the machine assembling process, is largely conditional: a number of the classical dimensional chain theory assumptions in practice give an error, which requires individual selection methods during assembly, including adjustments and fits for composite parts [5].

Non-rigid dimensional chains - dimensional chains where under the influence of internal and external factors in the dimensions of constituent links there are reversible/irreversible changes, which affects the value of the closing link formation. As a result, the acquired products size depends on different factors such as the elastic/plastic characteristics of the materials, the actual dimensional chain links values, the surface layer quality, the deviations of the contacting surfaces, the values of the forces applied to the parts during the conjunction process, the value of the other parts deviations. They form the dimensional chain not directly, but affect the part rigidity and deformation at its final assembly level and at the exploitation stage. Thus, since the existing theory of dimensional chains does not allow to fully evaluate and to study the dimensional connections during the assembly process or in the operated machine, the output parameters are properly controlled only on a fully assembled product.

Ensuring the assembliability of engineering products with composite components without additional fitting work is an urgent task. In addition to high labor costs, the composite materials fitting work is a source of mass microfine dust that require special conditions to protect worker’s health. Such fitting operations may demand the partial disassembly of the product or its units to clean it from the resulting dirt.

Production performance and assembly quality increase in modern conditions can be achieved by creating a quality-controlled assembly process based on the reliable analytical methods of real non-rigid dimensional chains calculation and by developing new methods of the required assembly quality insurances. The emerging dimensional chains accuracy insurance problem of the specified non-rigid assembly can be solved by calculating such dimensional chains, taking into account all the significantly influencing factors.

To solve the problem of non-rigid dimensional chains calculation, it is necessary to identify and to analyze dimensional and physical connections which arrise during the assembly process. The non-rigid dimensional chain equation of an assembly in general[6] is:

$$Y = f_1(x_i) + f_2(x_i, z_i, \mu, E_d, p_a) + f_3(x_i, z_i, \mu, E_d, p_c, N, R_{\max}, R_p, \rho, b, v, H_B, R_B, \sigma_T) \qquad (1.1)$$

where Y – the controlled size which also is the closing link of the dimensional chain; x_i – the actual dimensions of parts included in the dimensional chain; z_i – the actual dimensions of parts which are not included in the dimensional chain, but that affect total volumes and contact stiffness; μ – the part material Poisson's ratio; E_d – the part material elasticity modulus; p_a and p_c – the nominal and contour pressure on the contact area; N=$H_\mu$surf/$H_\mu$nom – metal surface layer hardening degree; $H_\mu$surf and $H_\mu$nom – treated surface and workpiece raw material microhardness; R_{max} – the maximum height of the workpiece surface roughness profile; R_p – the distance from the ledge line to the middle profile line (asperities smoothing height); ρ – the asperities peaks rounding radius; b and ν – the exponential approximation parameters of the initial area curve contact surface asperities; R_B – the surface waves radius; H_B – the surface waves height; σ_T – the component material yield strength.

In the formula (1.1): (*f*1) is the real part size in the considered dimensional chain link (in the classical dimensional chain theory, the dependence $Y= f(x_i)$ is known); (*f*2) takes into account all insufficient rigidity deformations of dimensional chain parts (the dependence of these deformations value on the above parameters is considered in the science of materials resistance); the (*f*3) considers the dimensional chain deformations due to the insufficient stiffness of the mating parts joints. The contact connection displacements types that are relevant to the above parameters in the set of an assembly parts joints are considered in the works of N.B. Demkin, I.V. Kragelsky, A.G. Suslov, E.V. Ryzhov and many other authors [7-10].

As a result of a variety of reasons in non-rigid dimensional chains there are constantly significant changes in the constituent units dimensions and relative positions, it is necessary to consider these dimensions as variables:

$$x_i = f(E,\sigma,v,T,\tau,F) \tag{1.2}$$

where E is the magnetic field; σ is the magnitude of the residual stresses in the component surface layer; *v* – the details voltage, T is the ambient temperature; τ – the part work time; F – the external force acting on the part [6].

3. Chapter 2: Elastic properties of fibrous composite materials

Composite materials should be considered as an anisotropic element, which establishes a special kind of connection between stresses and strains. Thus, for thin-walled multilayer structures, the plane stress state and bending are typical, i.e. the transition from general relations for a linearly elastic anisotropic body to particular forms of their recording for these stress states is important. Then Hooke's law for such elements according to [11]:

$$[\varepsilon]=[\mathrm{F}][\sigma] \tag{2.1}$$

where the matrix [F] is defined by the dependency:

$$[\mathrm{F}]=\frac{1}{E}\begin{bmatrix} 1 & -\mu & -\mu & 0 & 0 & 0 \\ -\mu & 1 & -\mu & 0 & 0 & 0 \\ -\mu & -\mu & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2(1+\mu) & 0 & 0 \\ 0 & 0 & 0 & 0 & 2(1+\mu) & 0 \\ 0 & 0 & 0 & 0 & 0 & 2(1+\mu) \end{bmatrix}. \tag{2.2}$$

For an isotropic three-dimensional body, the matrix [F] is invariant to the choice of the coordinate system and is formed using two constants E and μ, which entirely determine the elastic properties of the isotropic body. In the complex stress state of the isotropic body, the elongations ε_{ij} are independent of the tangent stresses σ_{ij}, when the shear angles Υ_{ij} are dependent on the corresponding tangent stresses σ_{ij}. In this regard, for the elastic isotropic body, the main stress state axes coincide with the deformed state main axes.

By solving the system of equations (2.1) with respect to stresses, Hooke's law can be rewritten as:

$$[\sigma]=[k][\varepsilon] \tag{2.3}$$

where $[k]=[\mathrm{F}]^{-1}$ is the material stiffness matrix:

$$[k]=\frac{E}{(1+\mu)(1-\mu)}\begin{bmatrix} 1-\mu & \mu & \mu & 0 & 0 & 0 \\ \mu & 1-\mu & \mu & 0 & 0 & 0 \\ \mu & \mu & 1-\mu & 0 & 0 & 0 \\ 0 & 0 & 0 & (1-2\mu)/2 & 0 & 0 \\ 0 & 0 & 0 & 0 & (1-2\mu)/2 & 0 \\ 0 & 0 & 0 & 0 & 0 & (1-2\mu)/2 \end{bmatrix}. \quad (2.4)$$

An elastic body is considered as anisotropic if its elastic characteristics differ in different directions, then any components of the stress tensor σ_{ij} can contribute the appearance of all components of the strain tensor. The malleability coefficients of an anisotropic material depend on the coordinate system position. In general, they form a completely filled matrix [*f*] of size 6x6. According to the body compliance on reciprocity theorem for the matrix components, when the condition $F_{mn}=F_{nm}$ is satisfied only when six diagonal and half non-diagonal components are independent – a total of 21 coefficients. Then Hooke's law can be rewritten in expanded form:

$$\begin{bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \gamma_{12} \\ \gamma_{23} \\ \gamma_{31} \end{bmatrix} = \begin{bmatrix} F_{11} & F_{12} & F_{13} & F_{14} & F_{15} & F_{16} \\ & F_{22} & F_{23} & F_{24} & F_{25} & F_{26} \\ & & F_{33} & F_{34} & F_{35} & F_{36} \\ & & & F_{44} & F_{45} & F_{46} \\ & \text{sym} & & & F_{55} & F_{56} \\ & & & & & F_{66} \end{bmatrix} \begin{bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{12} \\ \sigma_{23} \\ \sigma_{31} \end{bmatrix}. \quad (2.5)$$

The general form of anisotropy in real materials is rare. Most often, the structure of the material has identical elastic properties in some directions. Then the number of independent coefficients in the matrix [*f*] and [*k*] is reduced, as well as with a rational arrangement of the coordinate system, the recording of Hooke's law is simplified.

So in the source [11] are considered special cases for an orthotropic material, for a material with the presence elastic properties symmetry plane, for a transversal-isotropic body with an isotropy plane.

At the present moment, a lot micromodels related to the composite materials reinforced with straight fibers are developed, but it should be noted that all these models mostly agree with each other and with experiment only in the longitudinal modulus of elasticity values, and in relation to other obtained modules may differ from each other. That happens because the structure of the real material in fact may be different from the idealized, which is considered in the models. So when designing and calculating structures made of composites, it is rational to apply an experimental method for determining the physical characteristics of the material. In this case, obtained experimental characteristics guarantee the possibility of taking into account all the manufacture features of particular composite material.

4. Chapter 3: The integration features of the presented methodology with GePARD system spatial analysis

Single time assembly process refers to the design principles and assembly/adjustment implementation processes. That implementation guarantees required output characteristics of the product without additional work in the serial production process. An important criterion for the implementation of one is an adequate mathematical model of the assembly process and its design tools, for example, used in the GePARD system.

In the GePARD system developed at the Irkutsk National Research Technical University is applied own development concept of "the functional requirement" to an assembly on the tolerances model basis [12-15]. The functional requirements for the area is expressed in such nominal value deviations that provide functional dimensions of the product, and is expressed in the function [17]:

$$\left[F_r\right] = f(G,T,L) \tag{3.1}$$

where $G = \{g_1, g_2, \dots g_k / k \in N\}$ – the assembly geometry representing set; $T = \{t_1, t_2, \dots t_n / n \in N \cup \{0\}\}$ – the specified tolerance set; $L = \{l_1, l_2, \dots l_m / m \in N \cup \{0\}\}$ – the assembly constraints set. The function *f* for each functional requirement is determined by a mathematical model corresponding to its type. The mutual deviation vectors calculation algorithm for these mathematical models is stated in [18], and forms the configuration process of the direct modeling [16] – where the critical accuracy characteristics definition is applied.

A systematic approach to the assembly processes is determined by the final product functional quality and its components internal state linking. Taking particular features of the actual details basing (as a part of assembly units), components basing surfaces reception inaccuracies lead to change of their stress-strain state. In addition to the theoretical operating and the real operating loads, product is reorganized as an independent assembly system, which characterizes the difficulty of predicting high-tech products behavior. The system approach methodology explains the emergence of the above-mentioned assembly techniques as opportunities to compensate negative consequences of the idealization and the unaccounted natural interaction relationships set of the parts during the assembly process.

Summarizing the above, this development is dedicated to the adequate tolerances assignment/verification problem solution. It is also dedicated to identification of "critical places" in the characteristics of the assembly units, i.e. leads to the electronic models quality improvement and reduction of the engineering products testing time.

5. Conclusion

Returning to the question of the reliable methods and programs for the low-rigid dimensional chains calculation lack is expressed in the lengthening of designed product stages and constructive-technological preparation refinement of the serial production costs increase.

Accepting the global computer-aided analysis development experience to identify the methods and tools for solving different industrial problems such as optimal flexibility fitment insurances in the assembly [19,20], tolerances analysis [21] and synthesis [22], flexible components standardization [23], the assembly process optimal sequence choice [24] or pre-calculation of the adjustment processes [25], the partial calculation methods application of the dimensional chains with low-rigid components on the basis of the composite parts stiffness calculation provisions and reference [11], complementing the three-dimensional automated analysis of the GePARD system capabilities, we can control the process of composite parts assembly by applying information about the actual assembly parts set dimensions.

This scientific research result can be implemented in the GePARD system in the future: i.e., using information about the assembly units "critical parameters", we can deduce dependences of the controlled non-rigid composite part dimensions, and, ultimately, increase the level of the direct part assembliability control.

References

[1] Chase K W, Magleby S P, Glancy C G 1997 *Proc. 5th CIRP Int. Seminar on Computer-Aided Tolerancing (Toronto, Canada)* URL: http://adcats.et.byu.edu/Publication/97-4/cirp_2_7_97a.PDF

[2] Polini W 2011 *Geometric Tolerances. Impact on Product Design,Quality Inspection and Statistical Process Monitoring* (London: Springer) pp 39-68

[3] Pasupathy T M K, Morse E P, Wilhelm R G 2003 *Journal of Computing and Information Science and Engineering* vol. 3 pp 64-75

[4] Balakshin B S 1969 *Fundamentals of engineering technology* (Moscow: Mechanical Engineering) p 559

[5] Graham Warwick 1997 *European Project Tackles Composites Assembly Hurdle To Production*

Ramp-up (Toronto, Canada) URL: https://aviationweek.com/technology/european-project-tackles-composites-assembly-hurdle-production-ramp
[6] Suslov A G (Et al.) 2012 *High technology in mechanical engineering* (Moscow: Engineering) p 528
[7] Demkin N B 2004 *Mechanics and physics of frictional contact and boundary layers* (Tver: TSTU) p 136
[8] Ryzhov E V 1962 *Fundamentals of calculating the butt surfaces of machine parts for contact stiffness* (Moscow: Mashgiz) p 143
[9] Kragelsky I V 1968 *Friction and wear* (Moscow: Mechanical Engineering) p 480
[10] Suslov A G 1977 *Technological support for contact stiffness of joints* (Moscow: Nauka) p 102
[11] Skvortsov Yu V 2013 *Mechanics of composite materials* (Samara: Samara State Aerospace University) p 94
[12] Gaer M A 2004 *ISTU Bulletin* **4** p 177
[13] Gaer M A, Zhuravlev D A 2005 *ISTU Bulletin* **1** 116-125
[14] Gaer M A, Zhuravlev D A, Shabalin A V, Yatsenko O V 2009 *The collection of materials of the scientific and technical seminar "Advanced technologies and equipment for mechanical assembly production"* pp 103-107
[15] Gaer M A, Zhuravlev D A, Yatsenko O V 2011 *ISTU Bulletin* **10** pp 32-36
[16] Gaer M A, Zhuravlev D A 2012 *ISTU Bulletin* **11** pp 44-48
[17] Shabalin A V, Zhuravlev D A, Gaer M A 2013 *ISTU Bulletin* **12** pp 69-73
[18] Breteau P, Thiebaut F, Lartigue C, Fricero B, Falgarone H, Moufle GE 2007 Assembly simulation of flexible parts through the fitting of linkage devices. 10th CIRP International seminar on computer Aided Tolerancing: specification and Verification for Assembly, (Erlangen, Germany)
[19] Fricero B, Falgarone H, Chevassus N, Breteau P, Thiebaut F, Lartigue C 2011 Method for optimising adjusments of an assembly of parts under stress. Patent. Application number EP20090796727
[20] Fricero B, Thiebaut F, Stricher A, Champaney L 2014 Method for optimizing the tolerancing of a set of flexible parts subjected to forces. Patent. Application number US201214350067
[21] Andolfatto L, Lartigue C, Thiebaut F, Douilly M 2014 *Journal of Manufacturing Systems* **33(1)** pp 103-115
[22] Lartigue C, Thiebaut F, Bourdet P, Anwer N 2006 *In Advanced mathematical & computational tools in metrology VII. World scientific publishing* pp. 196-203
[23] Mounaud M, Thiebaut F, Bourdet P, Falgarone H, Chevassus N 2010 *International Journal of Production Research* 1366-588X pp 1-23
[24] Lacroix C, Mathieu L, Thiebaut F, Douilly M, Falgarone H 2014 Numerical process based on measuring data for gap prediction of an assembly. *13th CIRP Conference on Computer Aided Tolerancing* (Hangzhou, China) **27** pp 97-102