Using a discrete product model to determine the design element junctures

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Abstract. This paper describes a discrete model of a standard airframe part. The model is intended for determining the junctures between the design elements of a node (unit) in the pre-assembly procedures. We herein propose an algorithm selecting base surfaces for basing the product being assembled; selections are made on the basis of the 3D model of such product.

1 Introduction

Making pre-production processes (PPP) more efficient has recently become one of the most relevant questions. The current trends of scientific and technical progress enable significant enhancements in many areas of mechanical engineering, including aircraft building; however, assembling still involves intensive manual labor, slowing down the development of this industry as a whole.

The current state of the art allows for using various software packages to make pre-production processes in engineering more efficient.

2 Relevance and scientific importance

In pre-production, the main objective is basing the part, i.e. ensuring it is positioned correctly. After a part is based, it must be locked. To ensure it does not move in the chosen coordinate system, you must impose six bilateral geometric relationships, for which they would need a set of reference anchor points. If one or more of them is missing, the part will have one or more degrees of freedom. This means that, in the direction of the missing anchor points, the position of the part will be determined by its juncture to another part.

3 Problem Statement

Two or more adjoining parts are referred to as joint parts. The surfaces in such a juncture are referred to as joint surfaces.

Each part is generated in its own coordinate system; when assembled in a single file, their coordinates are adjusted relative to the working coordinate system (WCS) of the assembler file, which means that before one can talk about the junctures, they have to know the minimum number of anchor points and the position of each part in the assembly, as these factors are crucial for basing.

4 Theory

Let us use a beam calculation model that holds for those structures wherein the size along one axis significantly exceeds their cross-section, whereby there is no abrupt change in the rigidity and the anchoring elements, as shown in figure 1.

Fig. 1. Rib wall

To determine the deflection of the part, let us select a stripe along the generatrix, where there is a uniformly distributed load q along the length and a pressing force at the anchoring points, as shown in Figure 2.

Fig. 2. Calculation chart for a rib wall

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Then, the maximum deflection in the middle is calculated using the formula (1), while the maximum distance between the anchor points is calculated using the formula (3).

$$w_{\max} = \frac{ql^4}{8EJ_x} + (\delta_{\phi_{py}} - \delta_{\phi_{em}}) = \frac{\rho Fgl^4}{8EJ_x} + (\delta_{\phi_{py}} - \delta_{\phi_{em}}), \quad (1)$$

where E is the first genus modulus of elasticity for the material of the part, MPa; J_x is the moment of inertia of the section relative to the axis $x-x$, m^4 ; EJ_x is the rigidity of the profile, $N \cdot m^2$; ρ is the density of the material of the profile, kg/m^3 ; g is the free-fall acceleration, m/s^2 ; F is the area of the profile cross-section, m^2 ; $\delta_{\phi_{py}}$ is the part manufacturing error, mm; $\delta_{\phi_{em}}$ is the manufacturing error of base anchoring devices of assembly fixtures, mm.

Using the formulas (3.2)

$$w_{\max} \leq w_{\text{don}}, \quad (2)$$

where $w_{\max}$ is the maximum deflection, mm; w_{don} is permissible deflection, mm. and (3.3.), we obtain:

$$l \leq \sqrt[4]{\frac{8(w_{\text{don}} - \delta_{\phi_{py}} + \delta_{\phi_{em}})EJ_x}{\rho Fg}}. \quad (3)$$

Substituting all the values in the formula (3), we obtain the maximum distance between the anchor points $l_{\max}$ for all the parts made from beam-type profiles.

If the part anchoring is vertical, the deformation caused by the pressing force and the deformation caused by the own weight of the part are less than the maximum deflection $w_{\max}$. For all of the cases where the preliminary value of the distance between the anchor points $l_{\max}$, thereby ensuring the rigidity of the parts in assembly.

To simplify the search for the location by the parts coordinate measurement point, let us calculate the point of the center of mass of the part g_u . The coordinates of the center of mass are always specified relative to the working coordinate system (WCS), which for the assembly units of aeronautical engineering parts shall coincide with the principal axes of the aircraft.

Using the movement matrix M_t relative to the working coordinate system of the assembler file.

$$M_t = M_r \times M_v,$$

Where M_t is the movement matrix; M_r is the rotation matrix; M_v is the transition matrix.

$$M_{\text{trans}} = \begin{bmatrix} xx_0 & xy_0 & xz_0 \\ yx_0 & yy_0 & yz_0 \\ zx_0 & zy_0 & zz_0 \end{bmatrix} \times \begin{bmatrix} x_v \\ y_v \\ z_v \end{bmatrix} = \begin{bmatrix} x_0 + x_i \\ y_0 + y_i \\ z_0 + z_i \end{bmatrix}.$$

Accordingly, the coordinate placement of the other parts of the assembly unit shall be calculated by the center of mass relative to the working coordinate system of the assembly.

5 Practical significance and experimental results

The position of each part is now known, and we can start determining the junctures of the parts of the assembly unit. In essence, the principle is still valid that was used to identify the inter-element linkages to determine the structure of the part.

For instance, for parts 1 and 2 that are sets $M1$ and $M2$ consisting of i surfaces p_i , each surface contains at least three points, but in fact it has many more points; therefore, we get a set $M_i = \{p_1, p_2, \dots, p_j\}$ consisting of subsets $P_i = \{g_1, g_2, \dots, g_j\}$, where g_j is a point belonging to the surface.

Fig. 3. Junction surfaces of the parts in an assembly unit

In this case, the subset of points $\{g_1, g_2, \dots, g_j\} \in p_1$ ($M1$) and $\{g_1, g_2, \dots, g_j\} \in p_2$ ($M2$), i.e. the subset of points g_j is coincident for surfaces of different parts p_1 ($M1$) $\cap$ p_2 ($M2$), which in its turn means these surfaces are juncture surfaces, and parts 1 and 2 are joint through these surfaces $p_1 \subseteq M1, p_2 \subseteq M2 \Rightarrow M1 \cap M2$.

Fig. 4. Junction of parts in an assembly unit

To determine that the subset $\{g_1, g_2, \dots, g_j\}$ is the common subset for surfaces p_i of different parts, we compare the coordinates x, y, z for all g_j , and if the coordinates coincide, the points coincide, too.

As a result, we come to know the position, the surfaces, and the junctures for every part in the assembly unit; taking into account the first analysis, we know all the lines, all the existing surfaces, and even the points. Each

of those primitives is a base (assembly base, technology base, or design base); however, it does not make sense to use all of them; we have to single out the bases that are relevant to the problem to solve.

5 Conclusion

Using a discrete product model to determine the design element junctures allows for determining:

- the structure of the product;
- the design and technological parameters of the product;
- the set of the bases of the product.

It also makes it possible to obtain data for identifying the relevant bases to later solve the problems related to designing the technological tooling for product assembly.

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