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Technical paper

Quality- and cost-driven assembly technique selection and geometrical tolerance allocation for mechanical structure assembly

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ABSTRACT

The assembly process planning has been the subject of extensive scientific work, mainly due to the multiple aspects involved from geometrical matters to operational research concerns. However, very few issues about assembly technique selection are addressed. The aim of this paper is to propose a method to select an assembly technique for each joint of a product and to allocate geometrical tolerances accordingly. This is achieved by solving a multi-objective optimization problem to minimize the cost and the non-conformity associated with the assembly plan. The potential benefits of the method are illustrated on a case study representing the assembly of a simple mechanical structure.

1. Introduction

The design of the entire manufacturing process of a product – and more particularly the assembly process – has a key impact on the performance of an industrial company. When it comes to mechanical structures composed of a high number of components, like aeronautical structures, choices made for the assembly process account for a large share in the total delivery cost and geometrical quality of the assembled products.

A complete assembly process plan is supposed to describe entirely how the product is assembled out of the given components. As pictured in Fig. 1, it includes the assembly sequence, the selection of the assembly techniques, the geometrical tolerance allocation on the component and the design and organization of the assembly system. The assembly process planners have to reach several objectives generally expressed through various performance indicators.

Many efforts have been made to develop assisting solution for assembly process planning. Several methods have been proposed in the literature to evaluate (direct problem) or to optimize (inverse problem) assembly process plans. But these methods are generally limited to a single aspect of the general problem – such as sequence planning or tolerancing – and a single performance indicator.

This paper aims at proposing an original method to select assembly techniques and to allocate geometrical tolerances on components by solving a multi-objective optimization problem to minimize cost and maximize quality.

1.1. Assembly sequence planning and organization

Extensive work has been conducted to assist the generation of assembly sequences [1]. Bourjault [2], De Fazio and Whitney [3] and Dini et al. [4], among others [5–7], presented the assembly sequence as the ordered list of components introduced into the assembly. Homem de Mello and Sanderson also considered the concept of attachment [8], what led to the design of assembly sequences defined as the order in which the product's links and joints are made [9].

This joint-based approach reflects from some point of view the assembly task decomposition proposed by Cao and Sanderson [10] which is itself close to the issues considered for the organization of the assembly system commonly treated in operational research [11].

Between those two problems, *i.e.* the generation of assembly sequences and the organization of the assembly system, the issues for assembly technique[1] selection [12] are seldom addressed in the

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[1] Also called *assembly process* by some authors.

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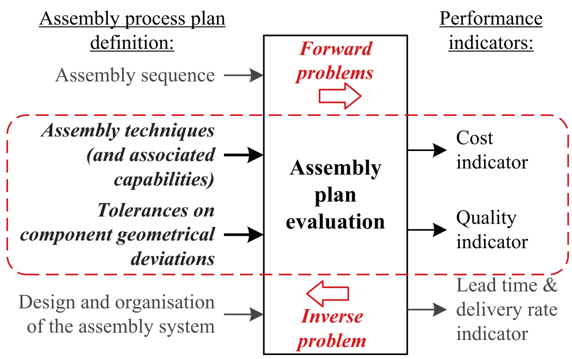

Fig. 1. Evaluation scheme of an assembly process plan, from plan definition to performance indicators (with the proposed approach bordered).

literature even though it may have the greatest impact on production cost, according to Abdullah et al. [13].

Almost all of the studies on assembly process planning aforementioned aim at minimizing lead time and/or cost, evaluated through various indicators such as, for example, tooling needs, reorientations of sub-assemblies, technological similarities in consecutive operations and so on [1].

1.2. Geometrical quality and tolerancing

The concern of geometrical quality of the assembled product is not commonly addressed by the assembly process planning community, even if the description of the geometrical variations of the components to be assembled may be part of the information contained in a comprehensive assembly process plan.

Nevertheless, the combined impact of the component geometrical variations, of the assembly technique capabilities and of the assembly sequence on the product geometrical quality was highlighted in several works related to tolerancing issues [9,14,15].

Chase et al. dealt with component manufacturing process selection to satisfy geometrical requirements on the assembled product [16]. Adragna et al. proposed a tolerance allocation method that maximizes the assembly process capability index [17]. Ding et al. and Huang et al. presented process-oriented method for tolerance synthesis in multi-station manufacturing environment [18,19].

These studies aim at allocating geometrical tolerances to satisfy objectives on indicators of the geometrical quality of the assembled product.

1.3. Proposed approach

In the field of aeronautical structure assembly, making trades-off between automated and manual assembly plans proved to be very complex. The need for decreasing manufacturing cost and increasing delivery rate is usually solved by massive automation in other manufacturing domains, such as automotive industry. But this solution is not always compatible with the high level of geometrical requirements on aeronautical structures.

This paper focuses on a method to select assembly techniques and allocate component geometrical tolerances in order to minimize a cost indicator and to maximize a quality indicator associated with the assembly plan. Considering the assembly technique selection together with the geometrical tolerance allocation allows exploring a wide range of potential solutions.

This multi-objective optimization approach prevents from making decision *a priori* while it let the decision-making team select the most appropriate assembly plan among several *optimal* ones.

The assembly sequence (attachment-based defined) is considered to be predetermined – according to the method proposed in [20] for example. The detailed design and organization of the assembly system take place once the assembly techniques are chosen and are thus not considered in this study. The resulting boundary of the study is illustrated in Fig. 1.

The second section details the data structure used to define a parametric assembly plan, what is required to tackle its optimization. The multi-objective optimization set to solve the problem addressed in this paper is described in the third section.

Section 4 details the proposed evaluation of the assembly plan. The quality indicator is a conformity rate evaluated thanks to a probabilistic study based on the geometrical variation propagation relation associated with the assembly process plan. The evaluation of the assembly cost indicator combines operations and tolerances cost. The former relies on a simple activity-based analytical model applied on each operation. The latter is obtained thanks to a cost versus tolerance relation adapted from [16]. Cost and quality indicators' evaluation are both intentionally simple to let the reader focus on the global approach proposed for technique selection and tolerance allocation. These indicators can easily be replaced by more realistic ones for actual industrial applications.

The optimization method used is briefly described in Section 5.

The entire method is illustrated through a simple case study presented in Section 6 where results are exposed and discussed. It is followed by a conclusion.

2. Parametric assembly plan

2.1. Introduction

The inverse problem displayed in Fig. 1 is solved thanks to a multi-objective optimization. Therefore, the performance indicators of the assembly plan – the cost and the conformity rate in this study – must be expressed as mathematical functions (described in Section 3). The input parameters of those two functions must be parameters that describe the assembly plan to evaluate. This section explains how this set of input parameters is extracted from the description of the product and from the technical know-how of a company.

2.2. Structuro-functional model of a product

An assembled product is a set of components connected to each other thanks to assembly joints. Each joint involves two surfaces, each one belonging to one of the components. The structure of the product can be represented by an Elementary Contact Graph [21] (ECG). The joints can be classified into two categories: *mates* that pass dimensional constraints from part to part, and *contacts* that provide support and lead to hyperstatic assembly [9]. This classification helps building *datum flow chain* (DFC) to identify components and joints involved in the variation of the product's *key characteristics* (KC) [9]. A key characteristic is a property of a product required to satisfy a function. In this paper, we only consider KC expressed as geometrical conditions between two surfaces, even if the definition applies for any measurable characteristic.

Marguet proposed to represent components, joints (mates and contacts) and KC thanks to an Oriented Contact Graph that mixes Elementary Contact Graph and datum flow chain approaches [20]. This graph represents the structuro-functional model of a product. It was implemented in a software called GAIA® [22].

The Oriented Contact Graph can also represent temporary components used during the assembly, like tools and jigs. Joints between temporary components and components of the product are called temporary joints. They are all released at the end of the assembly.