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Parametric Variational Analysis of Compliant Sheet Metal Assemblies with Shell Elements

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Abstract

One of most demanding tasks in the manufacturing field is controlling the variability of parts as it may affect strongly the deliverability of key characteristics defined at the final (product) assembly level. Current CAT systems offer a good solution to the tolerance analysis/synthesis task, but to handle flexible objects with shape errors more effort is needed to include methods able to capture the elastic behaviour of parts that adds more variability on the final assembly. Usually, sheet metal assemblies require dedicated fixtures and clamps layout to control the gap between parts in the specific location where a join must be placed. Due to the variability of parts the position of clamps can also be varied. The paper describes a FEM-based method able take into account part flexibility and shape error to parametrically analyse sheet metal assemblies by acting on some key parameters to look for the optimal clamp layout that guarantee the gap between parts to be under control after joining parts together. This method offers, with respect to commercial solutions, the ability to model fixtures, clamps and different joint types with no matter on the node positions of the mesh. Locations of such elements are based on the shape functions defined at element (shell) mesh level and modelled as local constraints. So the user can generate a mesh without a previous knowledge of the exact positions of clamps, for example. This allows to conduit a parametric analysis without remeshing the surfaces and with no need to physically model the clamps. An aeronautic case study is described with a four-part assembly riveted on a quite complex fixture by using several clamps.

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1. Introduction

In the manufacturing context the paradigm "Right First Time" is becoming mandatory in many fields especially where the competitiveness is high such as in the automotive/aeronautic field and consumer goods field as well. To limit failures in the advanced stage of the design process a systematic approach is required to deliver high quality products as soon as possible.

In the last 20 years an increasing interest on variation analysis of compliant assemblies came out in the fields strictly related to the increasing need to better control the variability of both product and process involving flexible components. In the automotive/aeronautic field, about 40% of changes occur after releasing the design, so it is important not only to start with a good design but also to predict failures by setting process analysis and diagnostic to compensate in time parts and tooling variability [1].

In the contexts where many sheet-metal parts and assemblies are involved, the traditional approach based on the tolerance analysis/synthesis under the hypothesis of rigid body components, also with the support of mature Computer Aided Tolerancing (CAT) tools, is not enough to analyse the behaviour of flexible assemblies. Here more variability comes from the small thickness and the related elasticity, and the free shape of the parts. FEM-based methods are widely described in the literature to predict variations for a given part variation and a given assembly process, and some solutions are also provided to speed up the analysis of batch of parts

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and assemblies to take into account the statistical variability of the product/process.

Usually, sheet metal assemblies require dedicated fixtures to properly locate parts in such a way they can fit well the mating components before assembling them. Particular attention is required for those assemblies that need a tight control of the gap between parts: the shape variation (coming from the manufacturing process), combined with inner flexibility of the part, may require a challenging study of the fixture as well as of the clamp layout. In fact, shape errors related to "actual" parts (instead of the nominal ones usually adopted in the simulation studies) make the analysis more complex. This occurs for example in remote laser welding (RLW) process where, to guarantee a good quality joint, the gap between parts being assembled must be kept within a close range among other specifications. The effect of shape errors is not negligible. The statistical variability of the process also requires that the fixture design and the clamp layout are robust enough to well fit all the batch of the parts [www.rlw-navigator.eu]. For riveted assemblies similar attention is required to look for the "best" location of clamps which a minimum gap along the flanges and a lower reaction on rivets correspond to. In those cases a what-if study can be arranged by automatically changing some key parameters and analysing the effects on the key product characteristics (such as the gap between parts) to achieve.

This paper describes a FEM-based method able to analyse "actual" non-ideal sheet metal assemblies (modelled as shell elements) by changing some key parameters to look for the optimal configuration of clamps that guarantees the gap between parts to be under control after joining parts together. "Actual" is here highlighted because, starting from the nominal model of the parts, their variational shape is accounted by reverse engineering a set of real geometries for each component. This method is implemented in Matlab and offers, with respect to commercial solutions, the ability (I) to include variational models (instead of only nominal ones), and (II) to model fixtures, clamps and different joint types with no matter on the positions of nodes in the mesh. Locations of such elements are based on the shape functions defined at element (shell) mesh level and modelled as local (also non linear) constraints. So the user can generate a mesh to fit the geometry's features without a previous knowledge of the exact positions of clamps, for example. This allows carrying out a parametric study aimed to optimise the clamp layout without locally remeshing the surfaces and with no need to physically model the clamps.

The paper is arranges as follows: section 2 is related to the background about variation analysis of compliant assemblies; section 3 describes the methodology behind the parametric study for clamp layout optimisation; section 4 describes an application to an industrial case study, while conclusions are reported in the section 5.

2. Background on Variational Analysis of Compliant Assemblies

Variation Simulation Analysis (VSA) is an important step of the manufacturing process because it focuses on the analysis of all sources of variations which may affect the quality of the product and tries to simulate them to predict failures and faults. A specific attention is required for compliant assemblies as they add more variability to the joining process due to the parts' flexibility. In these cases, dimensional and geometrical tolerances alone cannot predict the real shape of the released assembly, as the elastic behaviour of the flexible parts may strongly influence how parts and (sub) assemblies deform. Only in the automotive body structure manufacturing about 37% of all assemblies involve compliant parts [2] and for sure this data needs to be increased looking at the modern manufacturing processes. In [1] the methodology called SOVA, Stream of Variation Analysis, is described to model, analyse and predict dimensional variability of both rigid and compliant assemblies earlier in the design stage of multistage manufacturing processes.

Finite Element Analysis (FEA) is usually adopted to capture the elastic behaviour of the parts.

Focusing the attention on a deterministic assembly with ideal shape parts it is possible, by using commercial FEA software, to run a complex and detailed simulation study including contacts between parts, non-linearities due to local high deformations or material properties, and different assembly sequences.

A real closer analysis should also consider the stochastic variability of the manufacturing process and then hundreds of FE analyses are required, following Monte Carlo approach. This is a very time consuming task solved in [3] with a method able to speed-up the calculation without loosing accuracy in the prediction, while other authors tried to solve it by simplifying the analysis as in [4] where the sensitivity matrix, relating variations at part level with variations at assembly level, is introduced. Similar approach is used in [5-8] for single- and multi-station assembly configurations, also taking into account contact interaction.

All these methods rely on the ideal shape of the parts being assembled. But the actual shape (coming from the stamping process) can have an important role in the control of the assembly variability as where a tight gap between parts must be guaranteed for mechanical strength or only for aesthetic requirements. In [9] a morphing mesh based approach is proposed to model the shape variability of parts through the control of some key points of the geometry. In [10] the authors proposed