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Design of fixture systems in automotive manufacturing and assembly

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Abstract. Fixture systems have a great importance in modern manufacturing and assembly because of the high number of scenarios in which they are used. Fixture design is a complex task since the system effectiveness depends both on position and type of locators. Several authors deal with the problem of determine the most suitable design for fixture systems but their investigation is commonly limited to the evaluation of the effects due to the locators' position. In the present work a design method is proposed to evaluate the fixture systems considering also the locators' type. Since it is possible to model the fixtures as multi-performance systems, the comparison is performed by introducing appropriate sensitivity indexes. The effectiveness of the design method is proved through the application to an automotive case study.

Introduction

A fixture system (FS) is a device composed by locators to rapidly, accurately and securely fix workpieces during the various steps of their manufacturing and assembly process.

FS design has a fundamental importance in engineering since it is often a significant bottleneck in manufacturing and assembly of complex products and processes. The FS design effectiveness depends both on the type and position of the locators. Different disposition of the same group of locators (i.e. system layout) and different types of locators placed in the same position (i.e. system configuration) lead to very different performances.

Since the FS design process is affected by an inherent complexity, Computer Aided Fixture Design (CAFD) tools have been developed in order to support it. The current scientific research on CAFD is focused on two main issues: how to represent and collect the design knowledge within computer aided environments and how to implement engineering methods for improving the performance of the industrial FSs [1, 2]. Anyway the FS enhancing process is very often limited to the system layout while system configuration is rarely taken into account [3, 4].

In the present work a design method is proposed for the best evaluation of both the system layout and configuration through sensitivity analysis. Moreover a computer aided environment is developed for the implementation of the method for an automotive assembly case study.

Fixture system design method

The design method is based on three steps. The first one deals with the definition of the parametric theoretic model which relates the functional goal of the FS (e.g. a gap position and orientation measured between two subgroups in an assembly process) to the desired tolerance field (i.e. tolerance goal) due to technological or quality specifications. Tolerances depend on the dimensional and geometrical variability of singular parts, due to their manufacturing process, and on the variability of FSs, depending on layout, configuration and tolerances on every locator. The second step is a numerical simulation of such relationships, realized through the statistical variation of the tolerances for various system layouts and configurations. A Computer Aided Tolerance (CAT) tool is here adopted. The last step performs a sensitivity analysis of the system configuration for every given layout, in order to identify the most suitable and robust FS design to achieve the functional and tolerance goals. Fig. 1 describes the method workflow.

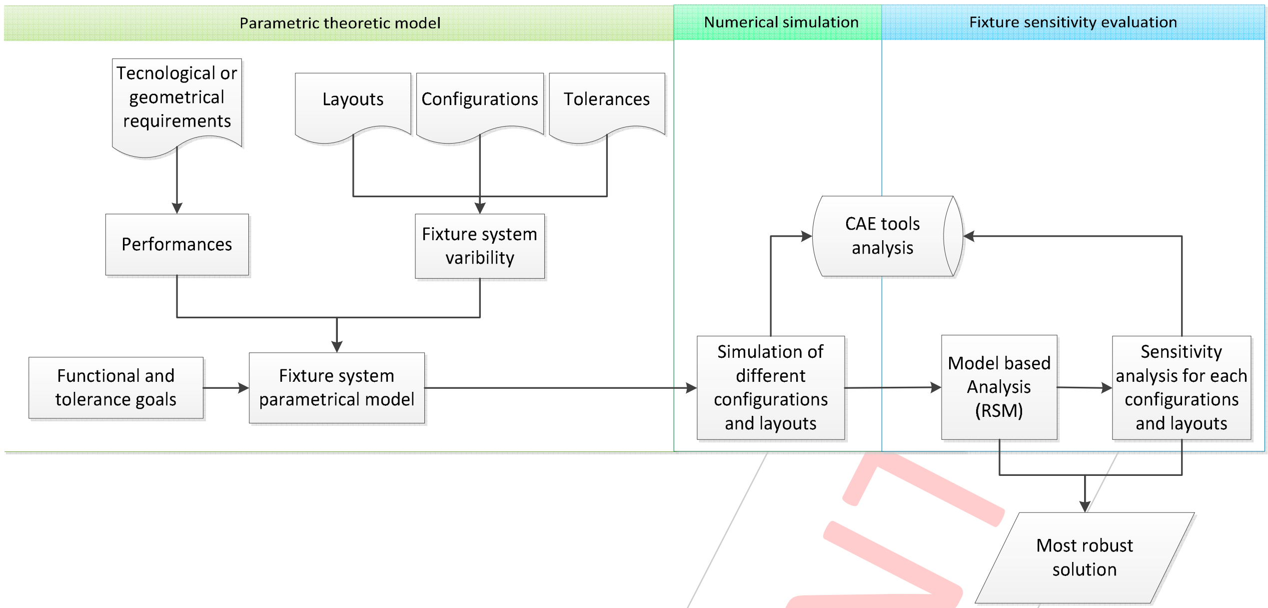

Fig. 1: Design method workflow

The FS configurations are evaluated through a model-based sensitivity analysis and the robustness of every FS configuration is measured thanks to sensitivity indexes, following the approach presented by the authors in [5]. The sensitivity indexes adopted are:

- Minimum value for the maximum eigenvalues of the Design Characteristic Matrix $\hat{\boldsymbol{\lambda}}_{\boldsymbol{N}}$;
- Maximum Feasible Space ($\mathbf{V_f}$);
- Minimum ratio between the Feasible Space and the hypervolume of the n-dimensional Tolerance Box ($\boldsymbol{\beta_u}$).

The method is a novel part of an extended computer aided approach for the design of reconfigurable systems for manufacture and assembly, also presented in [6], [7].

FS design for an automotive chassis assembly

A case study taken by automotive industry is investigated. The assembly of a subgroup for a top class car chassis is considered in order to demonstrate the applicability of the present design method in industry. Subgroups differ in materials (e.g. aluminum and cast iron), manufacturing processes and assembly technologies (e.g. welding, riveting, gluing). As a result, tailored FSs are specifically designed to accurately assembly the chassis subgroups.

The subgroup considered is composed of aluminum extruded parts, modeled in Dassault Systèmes Catia V5 and numbered from 1 to 6 in Fig. 2 left. The welding process imposes accurate target gaps between the surfaces of the parts to be assembled, as the gap shown in Fig. 2 right.

The industrial goal is the identification of the most robust FS configuration for the achievement of the target gap in the red square of Fig.2 left. As a first simplification, the FS layout is assumed to be imposed. Tolerances on parts and locators are known. Their variation is considered along the three directions Y (primary), Z (secondary) and X. Since the subgroup is built of rigid parts, the layout fully comply the 3-2-1 locating principle for every configuration.

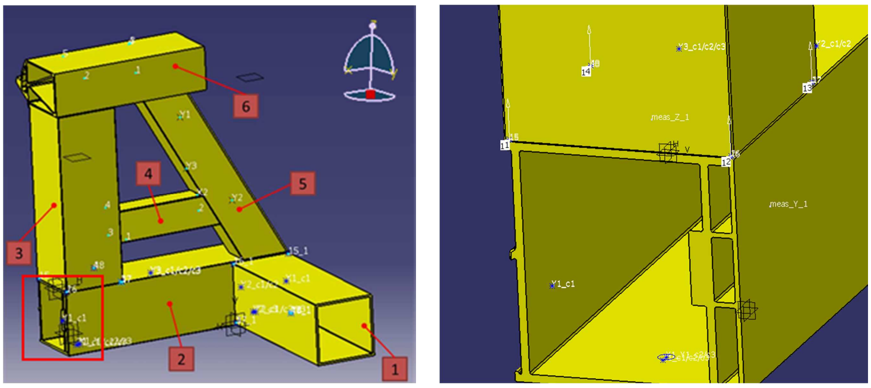

Fig.: 2: Subgroup of a car chassis (left) and target gap between two extruded parts (right).

According to such assumptions the following three system configurations can be proposed as a combination of pads and pins:

- Configuration1 (C1): 6 pads, one for each degree of freedom;
- C2: 4 pads and 1 pin/hole mate which restrains two degrees of freedom (X-Y);
- C3: 3 pads, 1 pin/hole mate which restrains two degrees of freedom (X-Y) and 1 pin/slot mate which suppresses the last degree of freedom (Y).

The first step of the study aims at connecting the technological gap between the parts of the subgroup (functional goal) together with the final value of the tolerance chain due to the dimensional and geometrical variability of parts and locators (tolerance goal).

During the second step a numerical simulation is realized adopting 3DCS-CAAV5. Suitable alternatives to the software used are presented and discussed, for instance, in [8] and [9]. Locators are modeled as contact points allowed to move along prescribed directions. In particular the pads are subjected to a position tolerance along one direction. Pins are modeled as contact points which can vary the position within a circular area with the center on the pin axe.

In step 3, multiple runs of the simulation, realized following a DOE plan, generate a second order response surfaces which describes the relationship between the values of the target gap variability and the tolerances of parts and fixture locators. According to such approach, the relative importance of each tolerance (factor) for every given configuration is measured. The diagrams in Fig. 3 report the results of the sensitivity analysis for the gap considered. The data coming from the DOE plan are split into two equal-sized groups, represented as colored squares. Such groups contain the minimum and maximum levels of each factor. The dimension of the squares represent the standard error of the mean. The importance of each factor is given by its shift in the response variable, i.e. the distance between the colored squares. In C1 the tolerance which leads to a higher shift is the tolerance of the pad along the Y direction. In C2 the most important factor is the pad tolerance along Y, and secondarily the pin tolerance along the directions Y and X-Y. In C3 the main factors are the tolerances on the two pins along the Y and X-Y directions.

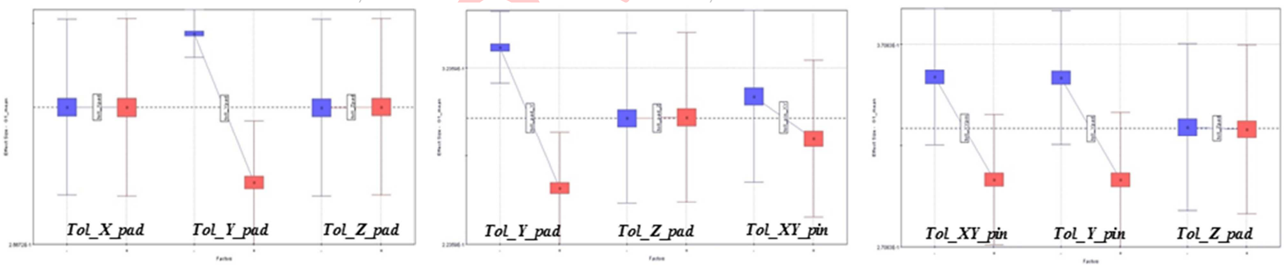

Fig. 3: Effect of the main factors for the gap in C1 (left), C2 (middle), C3 (right).

In order to evaluate the results from a robustness point of view, three sensitivity indexes are calculated, according to [5]. The values of the sensitivity indexes for the configurations are listed in Table 1.

Table 1: Sensitivity indexes for the system configurations

	$\boldsymbol{\beta_u}$	V_f	$\hat{\boldsymbol{\lambda}}_{\boldsymbol{N}}$ max
C1	0.4058	2.21E-04	1.7087
C2	0.2387	2.82E-04	1.4466
C3	0.1546	2.35E-04	1.0701

Configuration 3 presents the better combination of the indexes and represents the most robust solution for the case study considered.

Conclusions

The common approach to the FS design process is based on the evaluation of the layout system influence on the overall robustness. The authors present a design method aimed to evaluate FSs with respect to their configuration, i.e. the type of the locators adopted to reference parts during their manufacturing or assembly process. Anyway, the direct comparison between different type of locators is not possible because they are affected by different sets of tolerances. Nevertheless, it is possible to describe the FS functional and tolerance goals in terms of dimensional and geometrical variation of part and locators. Moreover, dedicated CAT tool can be configured and used to run numerical simulations to evaluate the influence of each tolerance contribution on the final target tolerance for many system layouts and configurations, varied according to a DOE plan. Since a FS can be considered as a multi-performance system, the comparison between the different configurations is performed by introducing proper sensitivity indexes.
A case study focused on a automotive chassis assembly is finally presented. The sensitivity analysis of the system configurations measures the effect of the type of locators on the robustness of the fixture systems.

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