

A Method for Locator Errors Compensation in the Fixture - Workpiece System

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ABSTRACT

Inaccuracies in workpiece location lead to errors in position and orientation of machined features on the workpiece, and strongly affect the assemblability and the final quality of the product. The accurate positioning of workpiece on a fixture is influenced by rigid body displacements and rotations of the workpiece due to locator errors. In this paper, a new mathematical modeling of a fixture - workpiece system is proposed to establish the relationship between the workpiece location error and its sources. For the purpose of eliminating the locator errors of the fixtured workpiece, the resultant errors due to several sources are modeled in the locator error. Then the displacement and rotation errors of the located workpiece can be compensated by adjusting the length of locators. The proposed method is proper for error analysis based on both worst case and statistical approaches. The application of the presented method is illustrated through presenting an example and the computational results are compared with the simulation results of the case study in a CAD system.

CITATION: Khodaygan, S., "A Method for Locator Errors Compensation in the Fixture - Workpiece System," *SAE Int. J. Mater. Manf.* 6(3):2013, doi:10.4271/2013-01-1382.

INTRODUCTION

Since the 1980's, computer aided fixture design (CAFD) techniques have been extensively developed. Fixture design is a complex problem that involves consideration of many operational requirements and has important connects with product quality and manufacturing cost. Fixtures are necessary elements of production processes as they are used to hold workpieces within most of the automated manufacturing, inspection, and assembly operations [1]. When a workpiece is located on a fixture for machining or assembly operations, errors due to several sources (e.g. setup errors and manufacturing errors such as machine vibration, tool-path errors, tool wear and tool deflection) affect the datum and target features on workpiece. Since inaccuracies in workpiece location lead to errors in position and orientation of machined features on the workpiece which strongly affect the assemblability and the quality of the product. Therefore, a fixture must accurately locate a workpiece in a specific position and orientation with respect to a cutting tool or measuring device, or with respect to another component, such as in assembly processes (e.g. in a welding process). Several researchers work on effects of locator errors on the product quality with the aim of proposing more precise methods for evaluating these effects. Rong and Bai [2] considered the dependence of machining errors and operations in a tolerance analysis approach to estimate the machining errors in terms

of linear and angular dimensions of a workpiece under a fixture design. Cai et al. [3] presented a method in sheet metal fixture design. A locating principle has been proposed and verified to be valid for deformable sheet metal parts as compared to the widely accepted "3-2-1" principle for rigid bodies. Cai et al. [4] developed a variational method for robust fixture configuration design to minimize workpiece resultant errors due to source errors. They utilized both first-order and second-order workpiece geometry information to deal with two types of source errors, i.e., infinitesimal and small errors. Choudhuri and DeMeter [5] presented a model that relates datum establishment error to locator geometric variability. The proposed model is limited to dimensional and profile tolerances in linear machined features that are bounded by planar workpiece surfaces. Rong et al. [6] presented a locator error analysis approach for set-up planning and fixture design that included three techniques; a fixturing coordination system was defined to simulate the actual locating situation, a vectorial tolerance zone definition was explored and a locator error evaluation algorithm was developed with sensitivity analysis functions. Carlson [7] derived a quadratic sensitivity equation by adequate dealing with locator contact at non prismatic surfaces, non-small errors, locator error interaction effects and locator errors in arbitrary directions. Zhang et al. [8] presents an analytical set-up planning approach with three techniques; an extended

graph to describe a feature and tolerance relationship graph and a datum and machining feature relationship graph, seven set-up planning principles to minimize machining error stack-up under a true positioning GD&T scheme; and tolerance decomposition models to partition a tolerance into interoperable machining errors. Sangnui and Peters [9] developed a mathematical model based on the Newton-Raphson technique to estimate the impact of component irregularities at the locating points on the location and orientation of a workpiece with cylindrical components. Wang [10] presented a mathematic method to estimate locator error in the contact zones of fixture-workpieces in which there are the locator positional error and workpiece datum geometric error. Kang et al. [11] used the Jacobian matrix to formulate the relationship between locating point displacements and workpiece displacement. The proposed method takes into account the error caused by both locator position error and locator deformation. Wang et al. [12] presented a method for kinematic analysis of fixtures based on the full contact model of rigid bodies. They considered the locator - workpiece contact area effects instead of applying point contact by introducing a contact matrix. Xiong et al. [13,14] and Deng and Melkote [15] developed fixture models and optimized the locator layout as the deterministic location is only one of the locating schemes being able to hold the workpiece in the desired position. Qin et al. [16] presented an analysis method that was able to characterize the effects of localization source errors based on the position and orientation of the workpiece. With this model, the locating principle and a criterion of the robust optimal design were proposed to improve the localization quality of the fixture. Chairapat and Rujikietgumjorn [17] developed a mathematical model to predict geometric variation of a resultant-machined surface when the tolerance of a datum feature is given. Armillotta et al. [18] proposed a method to carry out kinematic and tolerance analysis through a common set of geometric parameters of the fixture configuration. Based on the presented method, in a poor designed fixture, the analysis provides suggestions to plan the needed corrections to the locating scheme. Vishnupriyan et al. [19] presented a method based on the genetic algorithm that can simultaneously optimize both workpiece elastic deformation and geometric errors of locators. They developed a finite element model of the workpiece fixture system that obtained the elastic deformation of workpiece under machining loads. Cai [20] presented a tolerance modeling and analysis method through a two-step linearization with applications in automotive body assembly. The first step is to establish a linear relationship between the deviation input at locating sources, and the deviation output at on every single component in the assembly. The second step is to linearize the relationship between the first step output and the final assembly deviation output (such as gaps). Cao et al. [21] presented algorithms for workpiece positioning analysis under locator errors using the method of homogenous transformation. Workpiece constraint equations are solved

numerically for exact workpiece positional deviations by means of deterministic analysis and variation analysis. Wan et al. [22] provided a framework for abstracting an error model that integrates several errors of the located workpiece in machining processes into a unified one. Differential motion theory was used to build the evaluation model of errors. To eliminate the deviation, the resultant geometric variation was mapped into the locator errors on the fixture.

In this paper, a new matrix-based approach for estimating of the accurate position and errors of the located workpiece due to several sources is introduced. In order to reach to this aim, a mathematical formulation of workpiece-fixture behaviour during locating process is proposed to establish the relationship between the workpiece position error and its sources. In this method errors due to both the locators (geometric deviations of locator) and the workpiece (tolerances of the workpiece) are considered. Using the proposed matrix-based method, the actual position of produced features on the located workpiece can be estimated based on the worst case and statistical analysis approaches. The locator errors of the workpiece can be reduced and corrected by adjusting the length of locators. This method is straightforward in implementation and it can be easily automated.

SOURCES OF ERRORS

In this section some basic concepts necessary for the proposed model are presented. To establish a general fixture model describing the relationship between the workpiece position and orientation error and the localization source errors, variety of error sources should be considered. The major locator errors can be categorized in three types; locator geometric error (δr_l), workpiece geometric error (δr_m) and clamping error (δr_c) [16, 23]. These errors influence setup of the workpiece on the fixture and lead to the translations and the rotations (Δx) in the located workpiece. The existing of these errors is one of the most important reasons that the produced features on a machined workpiece fall out of tolerances after machining processes.

MATHEMATICAL MODELING OF THE LOCATED WORKPIECE ON THE FIXTURE LAYOUT

Consider a general located workpiece on a fixture as shown in Fig.1. Let XYZ system be the global coordinate system (GCS) and the i th locator be defined at "O" relative to it.

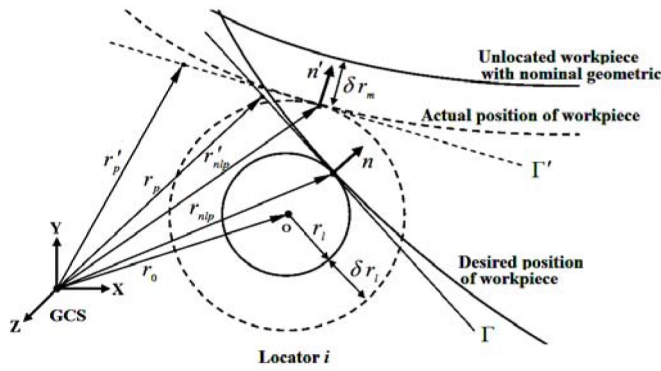


Figure 1. The schematic of normal and deviated tangent planes on a general workpiece

According to Fig.1;

n - The unit normal vector to the **nominal** tangent plane at the **nominal** point of contact.

n' - The unit normal vector to the **actual** tangent plane at the **actual** point of contact.

r_p - The position vector of any point existing on the **nominal** tangent plane.

r'_p - The position vector of any point existing on the **actual** tangent plane.

r_{nlp} - The position vector of the contact point between the workpiece and the i th locator at the **nominal** condition.

r'_{nlp} - The position vector of the contact point between the workpiece and the i th locator at the **actual** condition.

r_l - The radius of the locator i .

δr_l - The **locator error** due to the geometric deviation of the **locator radius**.

δr_m - The **workpiece error** due to the dimensional and geometric tolerances of the **workpiece**.

Γ - The **nominal** tangent plane.

Γ' - The **actual** tangent plane.

In this paper, the locator errors consists errors due to geometric deviations of locators (δr_l) and errors due to geometric deviations of the workpiece (δr_m). Since the radial error is the most significant error on the locators (e.g. locator wear) that affecting the position of the located workpiece, the locator errors are modeled based on the radial deviations of the locator. Therefore, the nominal locator and the actual locator are concentric and the proposed method does not consider the locator error due to the deviation of the locator position. However, this model can be extended to contain both the radial error and the position error of the locator. For mathematical modeling of locator errors in fixture layout following assumptions has been made; according to the fundamental principles of fixture design, the located workpiece is in contact with all the six locators which are

locating it. Secondly, the located workpiece is assumed to be rigid and do not deform by locating process. Moreover, the contact between the locator and the workpiece is assumed to be a point. The workpiece can be translated and orientated due to the errors on locators and the workpiece; this means that the nominal and actual contact points between the workpiece and the locators may be different. According to Fig.1, the nominal tangent plane to the workpiece with nominal geometry (without any geometric deviations) at the nominal contact point with locator i can be described by the following equation;

$$\Gamma : n \cdot (r_p - r_{nlp}) = 0 \quad (1)$$

where

$$n = [n_x, n_y, n_z]^T \quad (2)$$

$$r_{nlp} = [x_{nlp}, y_{nlp}, z_{nlp}]^T \quad (3)$$

$$r_p = [x, y, z]^T \quad (4)$$

In which $\cdot$ is dot product operator. In a similar way to derive the equation of tangent plane at nominal condition, the equation of the new tangent plane at the actual situation can be expressed as;

$$\Gamma' : n' \cdot (r'_p - r'_{nlp}) = 0 \quad (5)$$

The radius of the spherical locator i at nominal and actual situations are r_l and $r_l + \delta r_l$, respectively (Fig.1). Therefore, the position of contact point at the actual condition (r'_{nlp}) can be expressed;

$$r'_{nlp} = r_o + (r_l + \delta r_l) n' \quad (6)$$

where

$$n' = [n'_x, n'_y, n'_z]^T \quad (7)$$

The orientated unit normal vector (n') can be determined as

$$n' = \Omega \cdot n \quad (8)$$

where n is the unit normal vector of the nominal tangent plane at the nominal contact point and Ω is an orthogonal rotation matrix based on the Euler angles method that can be expressed as [24]