Design and Development of Welding Fixture for Sheet Metal and Structural Steel Fabricated Parts: A Review

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Abstract— In this paper main focus is to study the various things to be take in consideration while designing a welding fixture for sheet metal parts Fixtures control the position and orientation of parts in an assembly process and thus significantly contribute to process capability that determines production yield and product quality. As a result, a number of approaches were developed to optimise a single- and multi-fixture assembly system with rigid (3-2-1 fixture layout) to deformable parts (N-2-1 fixture layout). These approaches aim at fixture layout optimisation of single ideal parts (as define by CAD model). However, as production yield and product quality are determined based on a production volume of real (non-ideal) parts. Thus, major challenges involving the design of a fixture layout for assembly of sheet metal parts can be enumerated into three categories: (1) non-ideal part consideration to emulate real part; (2) 'N-2-1'locating scheme due to compliant nature of sheet metal parts; and, (3) batch of non-ideal parts to consider the production process error at design stage.

Key words: Welding fixture, N-2-1 fixture design optimization, Head end assembly, Compactor side bracket

I. Introduction

Fixture has direct impact upon welding quality, productivity and cost. Welding fixtures are used for holding different parts that have to be welded together. Other use of purpose of fixture is to reduce distortion that is generated during welding. It helps in reduction of production loss and also manufacturing lead time for welding, positioning and holding parts. Variety of residual stresses produced while welding is responsible for the distortion[4] Assembly fixture plays a significant role to achieve desired dimensional and joining qualities (Key Product Characteristics - KPCs) of assembled product where fixture design parameters act as Key Control Characteristics (KCCs). Fixtures are being used to provide accurate locating scheme to the demonstrated that fixtures have large impact on product dimensional and geometric / shape variation and, subsequently, on product yield (Phoomboplab and Ceglarek, 2008; Das *et al.*, 2014). This is especially true for assembly processes of sheet metal parts produced by plastic deformation processes which lead to significant shape variations (also called non-ideal part) due to mainly spring-back, forming process parameters variations, tooling errors. Additionally, due to the compliance of sheet metals, parts can get deformed and cause variation in assembly processes (Li et al., 2001). For example, excessive variations in automotive enclosure panels may cause fundamental problems such as unnecessary closing effort, improper fit causing vibration and noise, air leakage as well as poor aesthetic appearance due to misalignment (Ceglarek *et al.*, 2004; Camelio *et al.*, 2004a; Huang *et al.*, 2014). Subsequently, the shape variation management is a key issue in current industrial manufacturing and assembly process as it has direct impact on the product quality, cost and time-tomarket. To be competitive in the market, proper shape and part management through robust fixture design is inevitable prerequisite to minimize the defects caused by variation during manufacturing and product usage

The locating principle '3-2-1' is widely used in industries to locate rigid body parts quite uniquely without creating locator interferences (Lowell, 1982; Shirinzadeh, 2002). Variety of research literature exists in field of fixture design considering '3-2-1' part locating scheme which are mainly focused on designing and optimising fixtures for machining operations (Youcef-Toumi *et al.*, 1988; Menassa and DeVries, 1991). Further, Rearick et al. (1993) introduced deformable sheet metal parts and they proposed a technique combining the nonlinear programming and FEM for determining the best fixture locations. Beyond the first requirement of part placement and constraining the rigid body motion, the fixture should also be able to limit any part deformation. Unfortunately, compliant sheet metal parts cannot be controlled through '3-2-1' scheme which require increased number of locators to 'N-2-1' to minimise geometric deviation (N>3). For compliant part fixturing, Cai et al. (1996) proposed 'N-2-1' locating principle which allows to prevent excessive deformation of sheet metal parts by defining N locators on the primary datum. Camelio *et al.* (2004a) presented a new fixture design methodology for sheet metal assembly processes focusing on the impact of fixture position on the dimensional quality of sheet metal parts after assembly by considering the effect of part variation, tooling variation and assembly spring-back. A number of research focuses on joining process considering resistance spot welding and single part errors (Cai, 2008; Li et al., 2008a; Li et al., 2010; Liu and Hu, 1997). In case of laser welding, fixture plays a vital role by providing the degree of metal fit-up required to join the mating parts together. Li et al. (2001) proposed a prediction and correction methodology integrated with FEM for fixture design for laser welding where the objective function is to minimise the degree of Metal Fit-up (DMF), which is the maximum distance between mating nodes in weld joints.

Few attempts have been made over the years to optimise fixture design considering the metal fit up problem of compliant sheet metal assembly and the parts' shape variation (Li *et al.*, 2001). Undoubtedly, a batch of sheet metal parts produced through metal forming process may be affected by within batch or batch-to-batch variation which leads to quality loss of the final assembly. For example, some assembly joining processes, such as Remote Laser Welding (RLW), part variation strongly affects the final product performance which is imputed to part-to-part gap (Ceglarek, 2011). Therefore, a systematic fixture design approach is demanded to mitigate the part-to-part variation as coming from the real manufacturing process. Existing methods (Li *et al.*, 2007; Li *et al.*, 2003; Cai, 2006; Cai *et al.*,2005) for fixture design optimisation are based on single ideal/non-ideal compliant assembly models which are not sufficient to mitigate the error components associated with batch of assemblies.[1]

II. Fixture Design Methods

Jeng and Gill (1997) formulated a fixture design problem in hierarchical design structure. Mervynet al. (2003) presented an internet-enabled fixture design system by the use of XML file format. Rios et al. (2005) and Alarcon et al. (2010) developed and presented KBE (knowledge based engineering) application for, modular fixture design. Hunter et al. (2006) presented a functional design approach in which the functional requirements and constraints are considered as an input to the fixture design process. Wang and Rong (2008) and Sun and Chen (2007) presented the case based reasoning method to provide a computer aidedfixture design solution. Perremans (1996) developed an expert system for automatic fixture design [4]

III. Fixture Setup and Planning

Toumi et al. (1989) discussed the planning issues and presented the plans and requirements for automatic setup and reconfiguration of modular fixtures. Wu et al. (1998) developed the geometric analysis technique with modular fixture assembly to present the fundamental study of automated fixture planning. Kang and. Liu and Wang (2007) presented a hybrid approach in which machining precedence is determined by knowledge based and feature sequencing is through geometric reasoning for fixturing setup. [4]

IV. Fixture Optimization Methodology Overview

The proposed methodology is composed of three stages. Firstly, part shape variation is determined using part measurement data for batch of parts through quantifying the shape errors into few composite parts; and initial process configuration, i.e., joint locations, initial fixture locations (clamps, support blocks, locators etc.) are as initial process input.Thereafter, the finite element modelling for fixture simulation has been performed considering composite parts, fixture elements and contact pairs using Variation Response Method (VRM)software which is a Matlab™ based finite element modelling software toolkit with capabilities of fast modelling specific features required by assembly process (Franciosa *et al.*,2015). VRM is a new comprehensive methodology for dimensional management of assembly processes withcompliant non-ideal parts which allows to analytically model the product-toprocessinteraction. At this stage, fewer composite assemblies have been selected which quantifies the batch errors. Finally, the nonlinear optimisation has been carried out on the defined KPCs to obtain the optimised fixture layout by varying the KCCs (clamp locations). Optimiser updates the variables that are KCCs of the process to maximise the joining feasibility index [1].

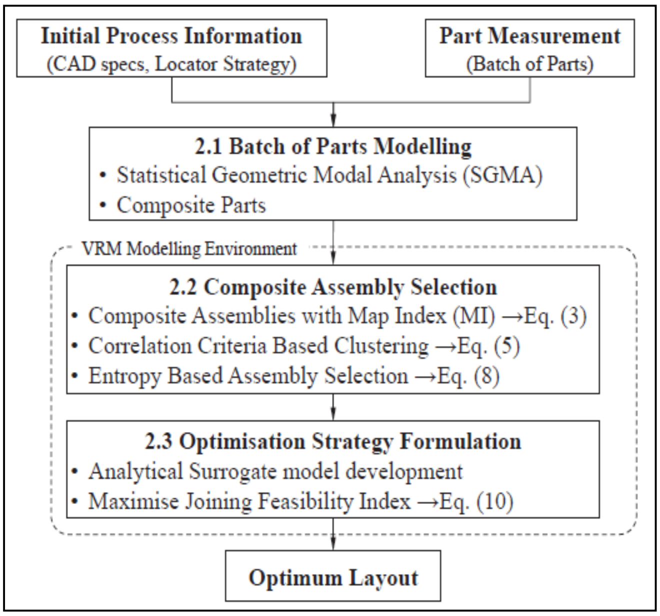

Fig. 1: Overview of Fixture Design Optimization Methodology

V. Design and Analysis of Fixture

A. *Material Selection*

The material selected for fixture is MILD STEEL. [4] Steel is any alloy of iron, consisting of 0.2% to 2.1% of carbon, as a hardening agent. What is known as mildest grade of carbon steel or mild steel is typically the variety which has a comparatively low amount of carbon (0.05% - 0.26%).

B. *The Properties of Mild Steel*

1) The density of mild steel is 7861.093 kg/m3.
2) Young's modulus, a measure of its stiffness is around 210,000 MPa.
3) Compared to other types of steel, this type is ideal for welding purposes, as it conducts electric current effectively without tarnishing the metal surface in any way.
4) Mild steel can be machined and shaped easily due to its inherent flexibility.

C. *Welding Fixture*

This fixture is use to locate the various plates on their respective positions on Base plate, with the help of which following operations will going to perform on component sequentially:

1) Perfect positioning
2) Proper aligning
3) Proper supporting
4) Welding

D. *Calculations for the Forces*

1) *Clamping Force*

It is the force to be applied in order to hold the plate in a vertical position.

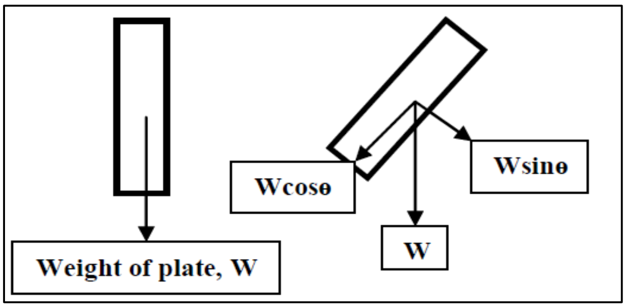

Fig. 2,3: Vertical Plate & Inclined Plate

Clamping force = WSinθ X g

Clamping force=200sin45×9.81 ………. (Assuming the inclination of 450)

Clamping force=1387.34N

2) Load on Baseplate of Fixture

Load on baseplate = weight of body when all plates are assembled

Load=2000×9.81

Load=19620N

Composite Assembly Selection[4]

VI. Composite Assembly Selection

Relying on the creation of composite parts and number of parts present in an assembly, several different composite assemblies can be created by considering the exhaustive combination of all composite parts below given equations.

KPC_s: $\{KPC_i\}$, $\lambda_i = 1,2,\ldots\ldots\ldots Nst$

Parts: $\{PT_m\}$, $\lambda_m = 1,2,\ldots\ldots\ldots M$

KCC_s: $\{KCC_l\}$, $\lambda_l = 1,2,\ldots\ldots L$

Composite parts : $\{CPT_{m.max}, CPT_{m,min}, CPT_{m,avg}\}$

Maximum Composite Parts : $CPT_{MAX} = \{CPT_{m.max.g}\}$

Minimum Composite Parts : $CPT_{MIN} = \{CPT_{m.min.g}\}$

Average Composite Parts : $CPT_{AVG} = \{CPT_{m.avg.g}\}$

Where $\lambda m = 1,2,\ldots\ldots$ m ; g= 1,2,…….Nm

Therefore, depending upon the number of clusters modelled for all the parts present in the assembly, the combination of composite assemblies also increases. The number of obtained composite assemblies can be formulated as

Composite Assembly: $CA= \{CPT_{MAX} \upsilon CPT_{MIN} \upsilon CPT_{AVG}\}$

As each fixture simulation is time expensive, optimization based on all composite assembly combination becomes computationally inefficient. Therefore, it emphasizes on selection of few composite assemblies which are representative of all other assemblies. In order to reduce the assembly number for optimization, two different criteria have been proposed: (i) Correlation Criteria Based Clustering and (ii) Entropy Based Assembly Selection.

VII. Welding Fixture for Head End Sub-Assembly of Motor Case

The model of the welding fixture for the head end subassembly is shown in the fig 4. This fixture is casted with aluminium considering the casting does not have a major effect due to the temperature rise because of the welding. Since, the heat evolved during welding is thrown out as soon as it is produced because of the purging facility provided under the weld bead. The critical part of the casting is the profile. This casted round profile has to match the profile of the dome, Y-Ring and also some part of the igniter boss. Hence, the fixture has to be inspected to match this profile to produce the required accuracy and tolerance of the welding on the components of head end sub-assembly. This has been stated in one of the paper that the dimensional accuracy of the welding fixture has a direct impact on the dimensional accuracy of the part being welded. Hence, to have a control over the required accuracy of the welding fixture is carefully casted and inspected before it is finalized to use as a welding fixture [1].

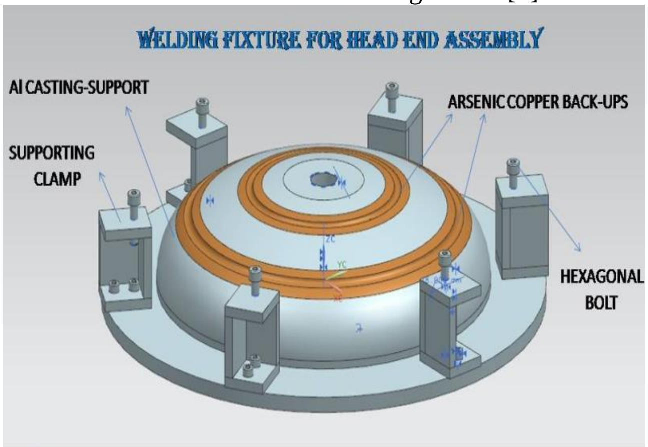

Fig. 4: Welding Fixture for Head End Assembly

VIII. Welding Fixture for Side Bracket of Compactor

Side bracket is a structural member which consists of two bending plates, one bracket (Irregular plate), and one stiffener, so the side bracket is made up of three members as mentioned above which are fabricated together to get a single structure. In order to fabricate these members welding technique is used. The side bracket is of two different kinds which are one is left hand, right hand side brackets. Instead of designing the fixtures for the LH and RH separately, we are designing common fixture for the both LH and RH bracket. Fixture assembly of side bracket mainly consists of base plate (on which remaining components are mounted), four swing locators, four rest pads, four locating pins & three screw clamps. [2]

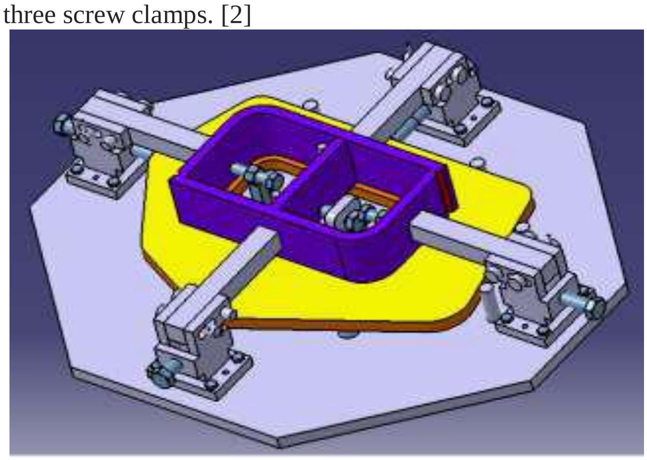

Fig. 5: Welding Fixture for Side Bracket of Compactor

IX. Conclusion

This paper has presented a new fixture design optimization methodology for non-ideal compliant assembly with batch of parts. The proposed methodology significantly explores the following areas:

1) Modelling of batch of parts with shape variation can be used for fixture design optimisation;
2) Fixture design optimisation considering batch of non-ideal compliant parts improves final assembly quality by reducing the impact of batch variation on product performances.

The above discussed methodology can be applied on other types of production fixture which involves compliant non-ideal sheet metal parts in various sectors such as automobile, aerospace, rail and home appliances. The modeling of each part of the head end sub assembly and the welding fixture is carried out better visual realization of the components, this modeling of the parts is modeled package UNIGRAPHICS NX 8.0. This method of modeling the parts evolves the better analysis towards the tolerances on the fixture design.

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