Available online at www.sciencedirect.com
ScienceDirect
Procedia CIRP 18 (2014) 221 – 225
www.elsevier.com/locate/procedia

International Conference on Manufacture of Lightweight Components – ManuLight2014

Fixtureless alignment of joining partners within the assembly of aluminum space frame structures

J. Fleischer[1], G. Lanza[1], S. Dosch[1], J. Elser[1], W. Pangboonyanon[1*]

[1] Institute of Prodction Science, Karlsruher Institute of Technology (KIT), Germany
* Corresponding author. Tel.: +49 (0) 721 608 47357; fax: +49 (0) 721 608 44005 *E-mail address*: Woramon.Pangboonyanon@kit.edu

Abstract

Light-weight aluminium space frame structures are frequently used for small-volume products, such as sports cars. The assembly of these products has so far been mainly manual and requires the use of complex and expensive fixtures. To increase the profitability, the research conducted at wbk Institute of Production Science is aiming to achieve an automated, fixtureless assembly of such structures by the use of industrial robots. To achieve the required accuracies regarding the alignment of the joining partners, a new approach based on component-inherent markings has been developed. This article describes the approach for the fixtureless positioning of components and the validation of the marking detection.

Peer-review under responsibility of the International Scientific Committee of the “International Conference on Manufacture of Lightweight Components – ManuLight 2014”

Keywords: Assembly; Automation; Flexibility; Alignment .

1. Introduction

The reduction of moving masses is of paramount importance for increasing energy efficiency of machinery, vehicles and equipment. Thus, lightweight designs will increasingly gain in importance. A possibility for weight reduction lays in the application of light supporting structures, such as for example aluminum space frame structures, which are already progressively used in the automobile and aviation industry [1-2]. At the same time, the automobile industry experiences a tendency towards considering individual customer demands. This leads to a greater diversity of variants and thus to a reduction of quantity [3-4].

Fully automated process chains that are able of producing various components without interruption are suitable for the cost-efficient production. For economic reasons, however, they are seldom applied when producing light supporting structures due to their lack of flexibility. Special devices or adapted machines are required for the assembly of space frame structures. Their application though is very expensive. To safeguard profitability, it needs to be done without those devices in the future. Therefore, the precise positioning of the joining partners in space constitutes a central challenge to the automated, flexible and to a great extent fixtureless assembly [5-7].

The precise positioning may be realized with flexible handling devices in combination with industrial robots. However, industrial robots do not operate precisely enough. They thus need to be supplemented by a measuring system for determining the exact position of the components to be joined. This scientific paper shall present a system for the fixtureless positioning of rotation-symmetrical components as well as its employability [8].

2. Requirements and state-of-the-art

Systems for the three-dimensional measurement and fixtureless alignment of joining partners must meet the following requirements [8]:

- For the assembly of space frame structures the position and orientation of several components must be measured and aligned in 6 degrees of freedom (x, y, z, A, B, C).
- Both, hardware and software must be useable for different components without requiring a machine

Peer-review under responsibility of the International Scientific Committee of the “International Conference on Manufacture of Lightweight Components – ManuLight 2014”
doi:10.1016/j.procir.2014.06.135

changeover or adjustments of the algorithms for the evaluation of the measurement data in order to provide maximum flexibility.

- The measurement and alignment of the 6 degrees of freedom are also carried out for rotationally symmetrical components, such as tubes or balls.
- The alignment process must be fail-safe and should allow the alignment of joining partner without force application, if possible.

Approaches that would meet these or similar requirements for fixtureless assembly processes with industrial robots have already been defined. However, these approaches are generally limited to specific applications and offer only limited flexibility. Some of the most important approaches are presented in [9-12]. These approaches use optical measuring systems to measure the spatial location and orientation of the components. In most cases, the detection process for the components is based on the identification of characteristic features such as edges and bores. When the shape of the component is known, it is possible to define the spatial location and orientation of the component based on this knowledge. Rotation-symmetrical parts, such as spheres and all profiles with a circular cross section, do not possess any characteristic features that could be measured accurately for a determination of the component orientation. Therefore, these methods are unsuitable for these kinds of components. Furthermore, the flexibility of the method is limited because the algorithms used for measurement data evaluation and sometimes also the hardware must be adjusted whenever a new and different component is handled [13].

To sum up, the most suitable approach responds to the individual characteristics. However, there is no approach that fulfils the demands of a fixtureless assembly of rotation-symmetrical components.

3. Approach for the fixtureless positioning of components

The following shall present an approach that allows the exact positioning of aluminum extrusion profiles towards each other as fixtureless as possible. The profiles' exact positioning during the assembly process is achieved with a component inherent scale. This scale is applied onto the extruded section's surface with a special marking laser in previously defined intervals.
Figure 1 shows the procedure for aligning the profile. The components to be positioned are pre-arranged by an industrial robot. Afterwards, the markings are read with a stereo camera system and the positioning of the components towards each other is evaluated. The subsequent positioning of one component to another is precisely carried out by industrial robots. This process is repeated until the final joining position has been reached [1], [14-15].

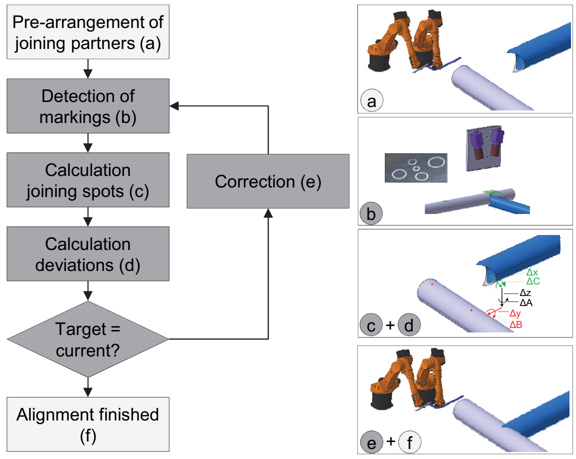

Fig. 1. Closed-loop system for three dimensional alignment of joining partners (6 DOF) with the target value of less than 0.1 mm in Matlab operation [8]

The following shall present the validation of the approach. For this purpose, the accuracy of the detection of the markings is determined first and the employability is derived from this value afterwards. Finally, the validation of the overall approach is presented.

4. Validation of the marking detection

In order to validate the process of the spatial arrangement of joining partners without any fixtures, the first step consists of performing a series of experiments to define the accuracy and the maximum coverage of the measuring system.

For the experiments, a stereo camera system was set up. The stereo camera system for the experiments is mounted on a five-axis micro-machine tool (figure 2). This installation allowed moving the components, on which the markings have been applied, and the measurement system relative to each other in a highly precise way. The markings for the experiments are applied on a plane and a round (radius 40 mm) aluminum part.

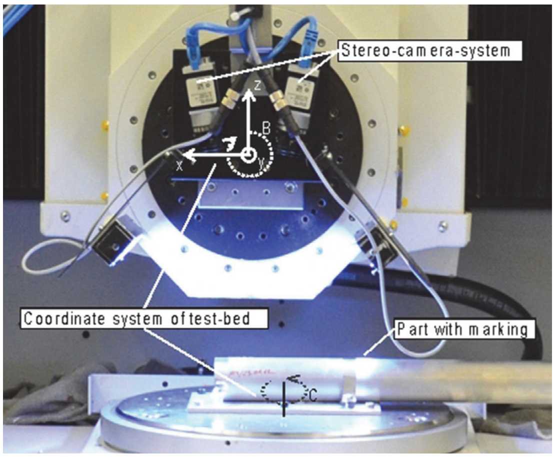

Fig. 2. Test set up for validation measurement system

For testing the measurement system and the measurement algorithms, the axes were examined separately and the position and orientation of the component are changed in steps of 5 mm and 5°, until the marking that has been applied on the part can not be captured anymore by the measurement system. The measuring of the B-axis from the perspective of the marking is performed by turning the component by 90 ° [13].

The average accuracy (mean deviation from the set points) in determining the translational positions (x, y and z) and the average accuracy in determining the rotations (A, B and C) are shown in table 1 [13].

Table 1. Average accuracy

	Plain surface	Round surface
x direction [mm]	0,0077	0,0039
y direction [mm]	0,0066	0,0079
z direction [mm]	0,0219	0,0064
A rotation [°]	0,0397	0,0057
B rotation [°]	0,0673	0,0981
C rotation [°]	0,0886	0,0763

These findings illustrate that the positions of the markings may be captured with an extremely high accuracy. Thus, the stereo camera system is suitable to be integrated into the overall approach.

5. Statistic validation of the overall approach

The validation of the marking detection in the measuring environment is followed by the validation of the overall approach which is performed by an industrial robot and a measuring device. The required tests are carried out by a prototype relative to a real production environment to implement the overall solution. For this objective, the system's smallest resolvable increment was determined first.

5.1. Determining the smallest resolvable increment

The smallest resolvable increment of the movement of the observed component is necessary for calculating the joining elements' trajectory when compensating the deviations as well as for determining the termination criterion when arranging the joining partners.

For this purpose, a straight round component with a radius of 20 mm was first moved along the x axis of the component marking in different increments. After that, the same was performed for orientation A around the z axis. The target values for the movement of the industrial robot lay between 0.01 mm and 0.1 mm or respectively between 0.01° and 0.1°. The actual distance travelled was measured with the laser tracker. The laser tracker's accuracy lays at ±16 µm. It should be noted that the measurement uncertainty of the laser tracker is not optimal for a desired alignment accuracy of joining partners. The accuracy of laser tracker though is not able to be achieved by other alterative measurement systems such as mobile coordinate-index arm as well. However, these measurement uncertainties are in an area which has no decisive influence on the result analysis in this paper. The measuring setup is depicted in figure 3.

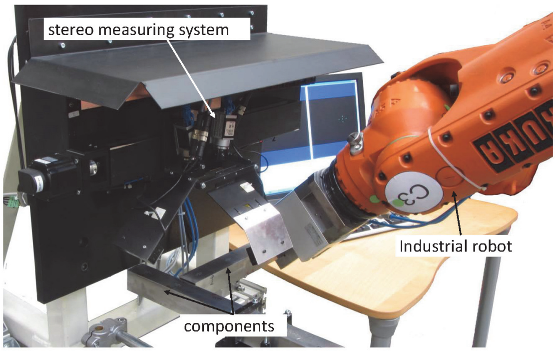

Fig. 3. Test configuration for validation of overall approach

This measurement setup positioned a straight round profile with a radius of 20 mm in varying steps along the x-axis. The target values were transferred to the industrial robot and the distance travelled was measured with a laser tracker. In this measuring setup, the smallest resolvable increment to be determined lay at 0.02 mm and 0.02°.

5.2. Spatial alignment of joining partners

The overall solution may be used for the exact positioning of joining partners in space if the components to be joined can be moved in a translatory and rotatory way with a defined amount. A statistical analysis has proven the ability for positioning. For this purpose, straight and bent round profile geometries were used for validation. Different positioning movements in the six degrees of freedom (x, y, z, A, B, C) are executed with the measurement setup described above. After each step, they are detected with the camera system and measured with the laser tracker.

The results of the distance accuracy DA of the covered increment are shown in table 2 together with the empirical standard deviation s_A. Furthermore, the industrial robot's actual movements are compared to the control's default values. This result is the value DI of the industrial robots' motion steps as well as the respective empirical standard deviation s_I.

Table 2. Reached accuracy for the straight round profile

	x [mm]	y [mm]	z [mm]	A [°]	B [°]	C [°]
DA	0,002	-0,001	0,021	-0,004	0,003	0,005
s_A	0,008	0,009	0,028	0,008	0,011	0,050
DI	0,000	-0,005	0,018	-0,002	0,001	0,002
s_I	0,008	0,011	0,024	0,007	0,007	0,026

The key values for determining the approach's employability were determined with the test set up shown in figure 3.

The determined values of the distance accuracy of the industrial robots' motion steps suffice for guaranteeing the approach's functionality. On average, the values for the reached distance accuracies lay at 0.005 mm (translations) and 0.065 ° (orientations). The permissible joint gap for the alignment of joining partner lays at ±0.1 mm. Thus, the reached distance accuracy results to be far better than the minimum requirements.

6. Examples of application

Different joining partners were selected and examined in order to validate the approach with real joining examples. Figure 4 depicts four typical types of joints of supporting structures. These supporting structures are only suitable for force free joining processes for example laser beam welding. Thus, friction stir welding is restricted [16].

The respective tests were carried out with the previously described prototypical test stand designed for actual production conditions.

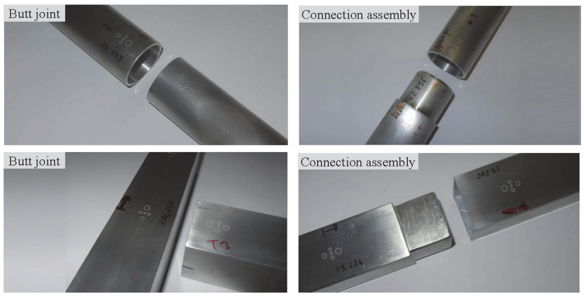

Fig. 4. Different connection types

In the final validation step of the solution for the fixtureless, automated spatial alignment of joining partners, the solution was applied for four connection types that are relevant for frame structures. All tests proved the employability of the solution for the alignment of joining partners towards one another.

After the alignment process, the maximum remaining gap between the joining surfaces measured 0.05 mm. On average, a remaining gap of 0.02 mm was achieved. Thus, this value lies fundamentally below the maximum permissible joint gap for joining operations of ±0.1 mm. This alignment accuracy allows higher assembly accuracy in compare to a conventional alignment with industrial robots. In General, the alignment of joining partners is conducted very close to the joining area. The tolerances of components have, therefore, a small impact on alignment accuracy [8].

7. Summary

A novel approach for the spatial alignment of joining partners has been developed at the wbk Institute of Production Science for the assembly of frame structures. The approach allows the alignment of joining partners without the use of fixtures. It is based on component-inherent markings. The approach entails the mathematic description of extrusion profiles on the basis of 3D coordinate systems, the design, detection and evaluation of component-inherent markings and an algorithm for the alignment of the component position.

The fact that component-inherent markings applied to the component surface are used represents an advantage because the location and orientation of rotation-symmetrical profiles, which are often used for frame structures, can be identified accurately.

Acknowledgements

The work is based on the investigations of the subproject C3- "Flexible material handling systems and measurement technology" - of the Transregional Collaborative Research Center/Transregio 10, which is kindly supported by the German Research Foundation (DFG).

References

[1] Ruch, D., 2010, Positions- und Konturerfassung räumlich gekrümmter Profile auf Basis bauteilimmanenter Markierungen, Shaker Verlag Aachen, ISBN: 978-3-8322-9684-1

[2] Friedrich, H. E., 2005, Werkstofftechnische Innovationen für die Fahrzeugkonzepte der Zukunft, „Vision Automobil“, 9. Handelsblatt Jahrestagung Automobiltechnologien, München

[3] Hu, S.J., Ko, J., Weyand, L., ElMaraghy, H.A., Lien, T.K., Koren, Y., Bley, H., Chryssolouris, G., Nasr, N., Shpitlani, M., 2011, Assembly system design and operations for product variety, CIRP Annals – Manufacturing Technology, 60:715-733

[4] Lien, T.K., Rasch, F.O., 2001, Hybrid Automatic-manual Assembly Systems, CIRP Annals – Manufacturing Technology, 50/1:21-24.

[5] Tekkaya, A.E.; Baier, H.; Biermann, D.; Fleischer, J.; Schulze, V.; Zäh, M.F.; Pietzka, D.: Integration von Umformen, Trennen und Fügen für die flexible Fertigung von leichten Tragwerksstrukturen – Der SFB/TR10, Ergebnisbericht der Phase II, Fortschritt – Berichte VDI, Reihe 2, Nr. 678, Düsseldorf: VDI Verlag 2011, ISBN 978-3-18-367802-0

[6] Munzinger, C.; Lanza, G.; Ruch, D.; Elser, J.; Gerbracht, T.; Köhler, G.; Ochs, A.; Schneider, M., 2009. wt-Werkstattstechnik online, Flexible Herstellung gekrümmter Strangpressprofile, p. 445-452

[7] Elser, J.; Ruch, D.; Schneider, M.; Köhler, G.; Gerbracht, T.; Ochs, A.; Marré, M.; Becker, D.; Selvaggio, A.; Huber, S.; Ruhstorfer, M.: Prozesskette zur flexiblen Herstellung leichter Tragwerksstrukturen – Steigerung der Qualität und Zuverlässigkeit. In: ZWF – Zeitschrift für wirtschaftlichen Fabrikbetrieb, Jahrgang 104, Band 6/2009, Verlag: Carl Hanser Verlag, München, Seite 442-449

[8] Fleischer, J.; Elser, J.: Spatial alignment of joining partners without fixtures, based on component inherent markings, In: Proceedings of the 4th CIRP Conference on Assembly Technologies and Systems, 20.-22.05.2012, Ann Arbor, Michigan, USA, 2012

[9] Bone, G.M., Capson, D., 2003, Vision-guided fixtureless assembly of automotive components, Robotics and Computer-Integrated Manufacturing, 19/1-2:79-87

[10] Jayaweera, N., Webb, P., 2007, Adaptive robotic assembly of compliant aero-structure components Robotics and Computer-Integrated Manufacturing, 23/2:180-194

[11] Watanabe, A., Sakakibara, S., Ban, K., Yamada, M., Shen, G., Arai, T., 2005, Autonomous Visual Measurement for Accurate Setting of Workpieces in Robotic Cells, CIRP Annals - Manufacturing Technology, 54/1:13-18

[12] Park, E.J., Mills, J.K., 2000, 6 DOF Localization of Sheet Metal Parts in Fixtureless Assembly Scheme, 31st International Symposium on Robotics, Montreal, Canada, 344-349

[13] Fleischer, J.; Lanza, G.; Otter, M.; Elser, J.: Spatial alignment of joining partners without fixtures, based on component inherent markings, In: Journal of Manufacturing Systems, Elsevier, http://dx.doi.org/10.1016/j.jmsy.2013.04.004, 2013

[14] Munzinger, C., Lanza, G., Ruch, D., Elser, J., 2010, Component-specific scale for inline quality assurance of spatially curved extrusion profiles, Production Engineering, 4/2-3:193-201

[15] Fleischer, J., Munzinger, C., Lanza, G., Ruch, D., 2009, Position and contour detection of spatially curved profiles on the basis of a component-specific scale, CIRP Annals - Manufacturing Technology, 58/1:481-484

[16] M. Zäh, M. Kronthaler, S. Huber, M. Ruhstorfer, F. Wirth, 2011. VDI Fortschritt-Berichte, Füge von Leichtbaustrukturen mittels Rührreib- und Bifokal-Hybrid-Laserstrahlschweißen, Reihe 2, Nr. 678, VDI Verlag Düsseldorf, 2011, p. 193-230.