Quality and productivity improvement through spot welding process optimisation in automobile body shop

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Abstract: Optimised geometry weld spot distribution for different configurations of automobile body sub-assemblies, is a critical activity in any automobile body shop process planning. For an ideal body shop planning, it has to be planned in a systematic approach so that the maximum productivity with high quality is being achieved. For this, the optimised planning has to be made for number of spots welded in a geometry station. The lesser the number of spots, the higher will be the dimensional variations of the assembly; the greater the number of spots, the lesser will be the productivity of the sub-assembly lines. The aim of this paper is to identify an optimised spot quantity for different sizes of parts with different surface contacts. To identify the optimum spot quantity, an industrial experiment was conducted using Taguchi method (L27 OA). Dimensional variations of the samples were recorded in two stages: 1) post-geometry spot welding; 2) post re-spot welding; and the measured data was thoroughly analysed. Recommendations for the optimised number of spots for geometry spot weld stage were made for different assembly configurations. These recommendations are discussed in detail. This study will aid the process planners to distribute the appropriate number of spots in the geometry welding stations.

Keywords: body-in-white; BIW; productivity; quality; geometry spot; re spot; Taguchi method; DOE; process optimisation; body shop; weld shop; surface contact; dimensional stability.


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1 Introduction

Quality and productivity are the two critical elements for any manufacturing facility. Shanin (2008) has studied and highlighted the role of quality in rising the productivity of operations. Bhamu (2012) has studied and explained about the productivity and quality improvement through value stream mapping. Rising quality and productivity are essential to meet the rising customer needs and also to maintain the operational costs at a minimal level. Manufacturing systems and quality management practices are found to be critical in maintaining competitive advantages (Lee and Park, 2016). Gorantiwar and Shrivastava (2014) has studied on critical success factors (CSF) and TQM concepts and also explained about the integration of the both to improve manufacturing quality. They have discussed about various critical factors that are involved in quality management, those factors with involvement of top management and stakeholders, factors that focus on continuous improvement, manufacturing strategy and policy, use of quality tools, process monitoring and production development. Lean manufacturing concepts emphasise the reduction of process time in the manufacturing facilities to optimise the resources. Mothersell (2008) has studied the brownfield conversion from mass manufacturing to lean production in a large automotive company. They have explained about the coherent transformational model for converting the brownfield facility into lean production facility. The following key technical components were considered in the lean conversion study, they are changes in the assembly layout, changes in TAKT time and jobs per hour (JPH).

Improvements or innovations for rising quality and productivity, happens independently, with or without significant effects of each other. In some cases, both have to rise together and this study is one among them. There have been more than one research conducted in the past on the analysis of body assembly dimensional variations; and the two major focused areas are:

1. assembly processes
2. resistant spot welding process.

Shiu et al. (2000) stated that “the dimensional stability increases the productivity and reduces the quality related problems. Welding process failure and dimensional variation are some of the major factors for decrease in productivity”.

This study is focusing on the appropriate geometry set process in body-in-white (BIW) assembly along with productivity rise. Automobile body welding process stages are generally classified as geometry welding stage and re-spot welding stage. Geometry welding stage is designed to set the geometry of an assembly at a particular stage where the following are to be ensured;
Quality and productivity improvement

1. There is no relative dimensional variation between the parts in the assembly even after it is released from the fixture.

2. The left out spots of an assembly can be taken in any of the consecutive re-spot station in the same cell or in a common re-spot station at a later stage.

In the current scenario, we could observe that there is no specific attention given to assign number of geometry spot for an assembly. In most of the cases, the geometry spots assigned are possibly more than the minimum required quantity to balance cycle time of a welding station unintentionally. Geometry stations are meant for geometry setting in which the available cycle time are ideally to be utilised to add more parts and weld the minimum preliminary spots to set the geometry. Adding more spots in a geometry station is a non-productive activity, compared to welding the same spots in a re-spot station.

As per Maynard operation sequence technique (MOST) cycle time calculation method, the average time taken to weld a spot in a manual geometry station is around seven seconds, whereas, the same spot in the re-spot station takes around 4.5 seconds only. Blockage of free access to the spots is one of the major bottle-necks in any geometry station. This is complemented by reducing the number of units in the re-spot station and hence there is a considerable process time difference between geometry and re-spot stations. Therefore, minimizing the geometry spots and shifting as much as possible to the re-spot station is very critical. Geometry stations fixture has various locating and controlling elements (risers, doily plates, cylinders, hoses, lifters, etc.) and those are normally located very close to each other with high density. Part locating strategy and number of parts are the driving factors for the fixture density. Re-spot fixtures are simpler in construction and it has minimum locating and controlling elements with better accessibility. Hence, it is easy to move the weld guns and complete the weld spots with lesser cycle time.

2. Literature review

Body assembly sheet metal dimension variations due to various welding sequences were studied and the author has recommended few design guidelines to the sheet metal designers to select the weld sequences to set appropriate Geometry. Design guidelines are provided to make stress free welding and stress relief patterns for different joineries (Shiu et al., 2000). The dimensional variation effects due to positional variation of spot weld was studied by Mali and Inamdar (2012) and he has concluded that, “spot weld position variation control is essential to maintain proper assembly dimensional accuracy”. Doshi and Desai (2016) has done a case study-based research to implement the statistical process control method in different suppliers and observed difficulties due to process variations; he has also identified the root causes for process variations. He has tried to resolve the process variations by implementing various action plans at supplier locations. His research gives us the indication of process variations possibilities in automobile manufacturing facilities. Carlson et al. (2014) has studied the weld spot distribution among the robotic welding stations and he has mentioned that the spot distribution between the robotic stations and sequence of spots plays a significant role in dimensional quality and throughput.

A computer-aided intelligent system was developed by Chen et al. (2006), which will automatically generate the optimal joint types and assembly sequences for the best
dimensional quality for any given assembly. This is an aid tool for designer to develop assembly joineries based on the existing library; a best suitable configuration can be obtained from the system. Phan and Matsui (2010) has studied the contribution of quality management and just in time (JIT) production practices to improve the production efficiency and flexibility in manufacturing facilities. Manufacturing process, layout, supplier, training of work force and scheduling are considered as main factors in the study. With the results it was concluded, that the plants which use quality management and JIT techniques achieve higher performance. Kumar and Kumar (2016) has discussed the need of lean manufacturing implementation to improve the operational parameters such as productivity, quality and cost. Quality control cost optimisation issue was studied by Liu et al. (2014) and recommended to decrease the rate of false alarm to improve the economic condition in body manufacturing. Complications of shimming in multi model lines to control body manufacturing quality was studied by Keller and Putz (2016) and recommended force controlled shimming method to overcome the manufacturing dimensional quality setting issue in multi model lines.

Cycle time balancing between body shop welding stations was carried out by Adham and Tahar (2011) with a multi model objective queuing method. From the developed model, two results were obtained. First, the process time balancing between the stations resulted in increased production quantity and saved 7.81 minutes per day. Second, the reduction in transfer lead-time which resulted in reduction of 5.81 minutes per day. Also, the author has mentioned that the lead time reduction was not focused in the previous investigations. Robot weld load balancing for multi model line was studied by Carlson et al. (2013) and proposed a novel generalised simulation-based method for automatic robot line balancing for robot positioning. Impact of different cycle times and buffer sizes of the body shop was simulated and validated with a case study by Spieckermann et al. (2000) and explained that the maximum utilisation of available cycle time with the possible reduction of production equipment. Optimisation of welding process and how it leads towards the quality in manufacturing was studied by Hardikar et al. (2012). He has taken an overview of various techniques used to achieve minimum distortion during the metal parts that are being assembled; and he has analysed and concluded that, “reducing dimensional variation is of critical importance to improve the final product quality”.

The literature review clearly describes that spot weld accuracy, position, sequence and number of spots plays a significant role in dimensional accuracy. Various researches were carried out so far with different approaches, to improve the dimensional accuracy in body assembly processes. And, the latest research of WärmeFjord states that, two spots are sufficient to lock the geometry between two parts. Adham and Tahar (2011) have explained about the importance of productivity improvement in body shop by reducing transfer lead-time and process-time balancing in body shop. However, BIW geometry setting and process optimisation are vast area and still lot of un-answered questions exists in front of us to resolve.

In this study, both geometry setting and process optimisation are integrated to obtain maximum productivity with appropriate dimensional quality. As per the previous studies, the minimum number of spots required to set geometry between the two parts are ‘2’. Further investigations are done in this study by considering four major factors to investigate the applicability of implementing the optimised number of spots across body shops with different configurations. This problem is studied using design of experiments (DOE) method. An industrial experiment was conducted with Taguchi (L27 OA) method and the samples were measured in coordinate measuring machine (CMM). Then, the
results were critically analysed for making the conclusion. Al-Refaie and Al-Hmaideen (2015) used Taguchi (L27OA) method for tableting process optimisation with three controllable factors, whereas, there are four controllable factors used in our study.

3 Research methodology

The following research methodology has been used to address the said objective.

1. The detailed literature review has been conducted in the area of body geometry setting. It has been concluded from the literature review to proceed with an industrial experiment, to observe the dimensional variations of spot welding process.

2. Taguchi (L27OA) experiment was planned with the help of MINITAB16 and the experiment was performed at a well-established production facility.

3. The door inner sub-assembly was considered in this study to generalise the problem. Total 27 set of experiments were performed and the samples were measured in both ‘after the geometry welding condition’ and ‘after the re-spot condition’.

4. The samples were measured in CMM and the results were recorded for both the conditions.

5. The dimensional measurement data has been analysed to observe the significant contribution of the defined factors. MINITAB16 software was used to plot the main effects of ‘means’ of the measured samples’ dimension variations.

6. The results have been critically analysed and the recommendations are presented in this paper.

4 Body manufacturing process and planning

Resistance spot welding is one of the general joining technologies used in automobile body shops to produce bodies. The total number of spots of a BIW varies between 3,000 to 6,000 with respect to its size and design. In a BIW, more than 200 parts are assembled together to complete a BIW. The total spots are distributed in the various welding stations of the body shop. Spot distribution between the geometry stations and re-spot stations is a process planning activity and also, it is a simultaneous engineering activity, which happens during product design stage.

The total number of welding stations in a body shop gets decided mainly based on:

1. total number of spot welds required to complete the body

2. TAKT time.

The major sub-assembly cells of a body shop are generally split into engine compartment/front end, front floor assembly, centre floor, rear floor/rear end, body side assembly, closure assembly and main line which includes under body assembly, main framing, re-spot, closure fitment and metal finish line (Figure 1). In the above said split up, spot weld process happens at all the cells except closure fitment and metal finish line. Each and every cell is having minimum one to maximum 6~8 welding stations in
sub-assembly lines and four stations to 15 stations in main lines. The total number of welding stations varies between 60 and 100 based on the production volume and JPH requirement.

**Figure 1** Body shop process flow

Process planning (or) process design is an activity to plan appropriate process, equipment and lay-out; and also it occurs during the product design phase in any new product development program. The number of welding stations for any body shop gets decided at this stage only. The process designers normally use the manual planning method or digital manufacturing techniques to design their manufacturing processes. In the planning activity, the total parts get distributed into different welding stations based on product assembly structure. While the parts are getting distributed among the stations, the next priority is to distribute the weld points among those stations. The process planners distribute the spots between the stations based on their experience (or) general practices that were followed in the previous projects, with the available database. In principle, the maximum possible spots get distributed in the geometry stations and the remaining spots are moved to the re-spot stations.

This is one of the major gaps observed in general practice of process planning. The geometry stations are not really meant to take as much as spots, it must be utilised to add as much as parts with optimised number of spot weld. It is important to understand that only the minimum number of spots required are to be considered, which will set the geometry and thereby we can achieve the appropriate quality as well as to increase productivity. Wärmejord et al. (2010) investigated on minimum spots required to lock the geometry of an assembly. Her investigation describes that, how the level of variation and deviation change with the number of executed welding points in a predetermined welding sequence. The author has concluded the result with an industrial case study, and has also explained in her conclusion that, “after two welding points were executed, the geometry was quite stable. So based on a geometrical point of view, two geometry points would be enough to use when assembling two parts”. However, Wärmejord et al. concluded the results with eight different parts of body sub-assemblies with simulation results and dimensional data measured using CMM. As a continuation on the study of Wärmejord et al. (2010), further investigation done with Taguchi method (L27 OA) with
the intention of identifying a minimum number of spots to set geometry for different surfaces contact parts with the different sizes and the same study with results are being explained in this paper.

5 DOE – L27 Taguchi method an overview

DOE was developed by Sir Ronald Fisher at the Rothamsted Agricultural Field Research Station in London in the early 1920s. Initially, he has used this method to determine the effects of various fertilisers on different plots of land. The final condition of the crop was not depending on only one factor of fertiliser but also other factors such as underlying soil condition, moisture content in the soil, etc. Ronald used DOE method to differentiate the effects of the factors and it was started using in various manufacturing experiments to improve process yield, process capability, profits and to reduce manufacturing costs, design and development time, scrap rate, defect rate and rework. The DOE is a technique used to define, data to be collected, quantity and experiment conditions, trying to satisfy two major goals: the statistical accuracy of the response and to lower the cost (Gunasegaram et al., 2009). Conventional experiment methods require more number of experiments to conclude the results and also are generally complex in nature.

In 1950s Taguchi developed a robust design to conduct experiment to simplify the experiment as well as to get appropriate results. One of the major advantages of this method is, that it reduces economically the variability of the response variable and it shows the best way to determine the optimum process condition during experiments. This is one of the important tools to improve productivity of any process (Ricardo et al., 2010). “Among the available methods, Taguchi design is one of the most powerful DOE methods for analyzing of experiments. It is widely recognized in many fields, particularly in the development of new products and processes in quality control” (Yuvaraj et al., 2012). “A large number of experiments have to be carried out when the number of the process parameters increases. To solve this task, the Taguchi method uses a special design of orthogonal arrays to study the entire process parameter space with only a small number of experiments” (Ugure esme, 2009).

It is observed that DOE methodology is used to solve various productivity and quality optimisation problems. Hence L27 (OA) Taguchi method is identified as one of the most suitable method to solve this problem.

6 L27 (OA) Taguchi experiment design

Considering the literature review and process design methodologies, the following factors were selected for the present work:

a spot quantity
b welding surface contact
c spot sequence
d spot position.
The levels of the selected experiment factors were established after analysing the observations of literature reviews and by conducting some preliminary experiments. The selected factors were kept stationary during the entire experimentation. Front door inner assembly was considered as experimental sample (Figure 2). Three different sizes of parts were considered in the experiment, to generalise the study for total body assembly (Figure 3).

- **Spot quantity:** in the previous study Wärnfjord et al. (2010) has identified that two spots were sufficient to set geometry between the spots. We continued the study by considering the recommended two spots for the initial level and further increased the levels with three and four spots combinations with respect to the different sizes of the parts.

- **Welding surface contact:** parts sizes and shapes vary with respect to design requirement, various sizes of parts are combined together to make an assembly. When two different parts are joining together, welding surfaces between the parts has, single surface in contact [Figure 3(a)], two surfaces in contact [Figure 3(b)] and three surfaces in contact [Figure 3(c)]; all the three possible contacts are considered in three levels in this experiment. Single surface contact part of 120 mm (L) × 84 mm (W) in size (10,080 sq-mm), two surface part of 110 mm (L) × 90 (W) mm (9,900 sq-mm) and three surface contact part of T section with 63 × 300 (L1 × W1) + 957 × 90 (L2 × W2) (105,030 sq-mm) of 1 mm thickness for all the combinations were taken (Figure 4).

- **Spot sequence:** previous studies of different authors have identified that the spot sequence is one of the most critical factors for dimension variation. By considering the fact of spot sequence influence in dimension variation, spot sequence is considered as one of the factor in our study also in three different classifications, such as:
1 close to principle locating points (CP)
2 middle to outer (MO)
3 out to middle (OM).

- **Spot position:** when the parts sizes are different in each and every assembly, spot position is also one of the critical factors to decide the optimal spot quantity requirement to set the geometry. Centre, diagonal and extreme were the three positions considered as the levels in this study.

**Figure 3** (a, b, c) parts considered for experiment (see online version for colours)

![Figure 3](image1.png)

**Figure 4** (a) Welding in single surface (X) (b) Welding in two surfaces (X, Y) (c) Welding in three surfaces (X, Y, Y1) (see online version for colours)

![Figure 4](image2.png)
7 Experimental set-up

This experiment was conducted in regular production welding fixtures and measured in two post coordinate measurement machine (CMM) to ensure the dimensional variation of the experiment samples. Experiment design and result analysis were carried out through statistical analysis software MINITAB16. Total 27 experiments were conducted with the sequence of Taguchi experiment design (Table 1). Parts were loaded in sequence and spots welded by satisfying the conditions planned in the experiment, such as, spot quantity, spot sequence and positions in all the three surface contact parts as per experiment design (Figures 5 and 6). Welded assembles were removed and moved to CMM room for measurement.

Table 1 L27 Taguchi experiment plan (see online version for colours)

<table>
<thead>
<tr>
<th>Trials</th>
<th>Spot quantity (A)</th>
<th>Welding surface contact (B)</th>
<th>Spot sequence (C)</th>
<th>Spot location (D)</th>
<th>Spot weld position, sequence for experiment and CMM check points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1 Close to PLP</td>
<td>CP – close to PLP</td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1 Close to PLP</td>
<td>CP – close to PLP</td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1 Close to PLP</td>
<td>CP – close to PLP</td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>2 Middle to outer</td>
<td>MO – middle to outer</td>
<td>Diagonal</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>2 Middle to outer</td>
<td>MO – middle to outer</td>
<td>Diagonal</td>
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</tr>
<tr>
<td>6</td>
<td>2</td>
<td>2 Middle to outer</td>
<td>MO – middle to outer</td>
<td>Diagonal</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>3 Outer to middle</td>
<td>OM – outward to middle</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>3 Outer to middle</td>
<td>OM – outward to middle</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>3 Outer to middle</td>
<td>OM – outward to middle</td>
<td>Extreme</td>
<td></td>
</tr>
</tbody>
</table>
Quality and productivity improvement

Table 1  L27 Taguchi experiment plan (continued) (see online version for colours)

<table>
<thead>
<tr>
<th>Trials</th>
<th>Spot quantity (A)</th>
<th>Welding surface contact (B)</th>
<th>Spot sequence (C)</th>
<th>Spot weld position, sequence for experiment and CMM check points</th>
</tr>
</thead>
<tbody>
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<td>Middle to outer</td>
<td>Extreme</td>
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<tr>
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<td>Middle to outer</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>12</td>
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<td>Middle to outer</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
<td>13</td>
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<td>Outer to middle</td>
<td>Centre</td>
<td></td>
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<tr>
<td>14</td>
<td>3</td>
<td>Outer to middle</td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>Outer to middle</td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td>16</td>
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<td>Close to PLP</td>
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<td></td>
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<tr>
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<td>Close to PLP</td>
<td>Diagonal</td>
<td></td>
</tr>
<tr>
<td>18</td>
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<td>Close to PLP</td>
<td>Diagonal</td>
<td></td>
</tr>
<tr>
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<td>Outer to middle</td>
<td>Diagonal</td>
<td></td>
</tr>
<tr>
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<td>4</td>
<td>Outer to middle</td>
<td>Diagonal</td>
<td></td>
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<td>4</td>
<td>Outer to middle</td>
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<td>Extreme</td>
<td></td>
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<tr>
<td>24</td>
<td>4</td>
<td>Close to PLP</td>
<td>Extreme</td>
<td></td>
</tr>
<tr>
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<td>4</td>
<td>Middle to outer</td>
<td>Centre</td>
<td></td>
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<td>Middle to outer</td>
<td>Centre</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>4</td>
<td>Middle to outer</td>
<td>Centre</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5  Right side door inner assembly welding fixture (see online version for colours)
Experiment was split into two stages. In stage 1, all the geometry spots planned in the geometry station as per the plan were welded and assemblies were measured in CMM and the variations were recorded (Figure 7). In stage 2, the remaining spots were taken in the same samples, after stage 1 measurement, in the re-spot station and again, the assemblies were measured in CMM to study the various relations and effects on the sub-assemblies’ geometry dimension between geometry and re-spot stations.

Experiment samples were measured after geometry spot weld condition and were measured again after completion of re-spots. The variations were recorded for analysis. ‘CARL ZEISS, CARMET C12 Horizontal arm double’ machine was used to measure the assemblies in a controlled environment. The global general allowable tolerance for:

1. sheet metal part is ± 0.5 mm
2. sub-assembly is ± 1 mm
3. complete body level is ± 1.5 mm.

Door assembly is in the category of sub-assembly process and hence ± 1 mm was considered as the allowable tolerance limit for the result analysis.
8 Analysis and discussions

The main objective of the analysis was to study the dimensional variation behaviour of all the three configuration of assembly parts with minimum two spots. The responses of the experiments were recorded and analysed through MINITAB16 software to conclude the study. MINITAB16 Taguchi analysis window and output graphs are given in Figure 8. ‘Means of mean’ and ‘signal to noise ratio’ were obtained to understand the main effects of all the four factors in the dimensional control of weld assemblies.

Figure 8 MINITAB16 Window (see online version for colours)

8.1 Observation after geometry weld

The samples were unclamped after welding in geometry station and inspected. There were no visual changes observed in single surface contact and two surface contact parts but visual defect was observed in three surface contact part (gap observed between the two welded surfaces), because, the size of the three surface contact part is larger than the other two parts. It was observed as 2.08 mm variation in the samples which were made with the configurations of 2 spots and spots were welded at extreme position of the sub-assembly; but the average variation range was observed as 1.7 mm (within tolerance of 2 mm range i.e., ±1.0 mm). In the same sample, 2~3 mm gaps were observed (Figure 9) in the middle portion of the welded surface, but the same gap was getting closed during re-spot welding and the average variation range became 1.1 mm, which is more close to the nominal (Allowable variation 0~2 mm). This scenario is evident in the graph [Tables 2(a) and 2(b)]. We could observe that there is a change in 3 surface welding compared to single and two surface matching parts. It shows that there is a significant difference in dimension variation when the surface contacts increase for 2 spots welding.
Figure 9  Gab observed between the weld surfaces (see online version for colours)

Table 2  Main effects of factors in Geometry and Re-spot weld conditions

<table>
<thead>
<tr>
<th>Measured axis</th>
<th>Axis dimensional variations observed in CMM measurement (all dimensions are in mm)</th>
<th>After geometry spot welding</th>
<th>After re-spot welding</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td><img src="a" alt="Diagram" /></td>
<td><img src="b" alt="Diagram" /></td>
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<tr>
<td>Y</td>
<td><img src="c" alt="Diagram" /></td>
<td><img src="d" alt="Diagram" /></td>
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<tr>
<td>Z</td>
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</tr>
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The visual defect did not play any role in dimension variation in this study, but it is not appropriate to move the assembly with unintended gaps, from the geometry station. There were no similar condition observed in three spots and four spots welded samples of three surface contact assemblies.

In this study, one of the major observations was that the dimension variation is very minimum in ‘X’ axis, which is perpendicular axis to weld spot and has the four way control with tooling pin, rest mylars and clamping control. The mean shift observed in ‘Y’ and ‘Z’ axis from ‘mean of means’ 0.5 mm to 1.0 mm in re-spot; it shows the other two axis parallel to spot weld gets disturbed during welding [Tables 2(c), 2(d), 2(e) and 2(f)]. There is no deviation observed in the ranges of spot quantity, spot sequence and spot location but there is a significant difference in the ranges of surfaces (single, two and three).

8.2 Observation after re-spot weld

Dimension measurement was carried out on geometry spot welded assemblies and the results were recorded; then the assemblies were moved to re-spot station to complete all the designed spots of door assembly. Then, the finished assembly was again moved to CMM and the same points were measured once again to observe the differences in dimensional variation behaviour between the geometry and the re-spot stage welded condition. In the geometry stage, the variations were observed within 0.5 mm in all the three spot configuration (of the available 2, 3 and 4 spots configuration) and 0.2 mm variation was observed after re-spot condition in all three configurations (Figure 9). Although there is a significant difference observed between two spot weld condition and three, four spot weld conditions in three surface contact part, the same were observed to be within the allowable limit 0–2 mm.

Three different types of the parts in two sizes were considered in the study; namely single surface contact part, two surface parts of similar sizes and the three surface contact parts of a comparatively larger size. In the observation, there is no significant difference observed between the single and two surface contact parts; hence, by considering the experiment result, two spots are appropriate to set the geometry for single and two surface contact parts. But there were variations observed in the three surface contact samples because of its size and number of surfaces factors. Hence, it was recommended to weld minimum of three spots with middle to outer (MO) and extreme positions to get the best results to set the appropriate geometry for the three surface contact parts.

9 Conclusions

The objective of this study was to find an optimised spot quantity to set the geometry in geometry welding stations. Accordingly, the following were observed in the thorough experimental analysis on the results obtained.

1. The variations were observed to be slightly more in the larger dimension part with three surface contacts after geometry stage welding. But the same were observed to be within the tolerance range after re-spot stage welding.

2. Number of surface is playing a significant role in deciding the number of Spots for any assembly.
3 There is no significant effect due to spot sequencing. But close to principle locating points PLP (CP) and MO spots sequencing are comparatively better than outer to middle (OM) spots sequence.

4 There is no significant effect observed in this study with respect to spot position (middle, diagonal and extreme).

5 Based on the above observations, and by considering the concept of setting the geometry in the geometry station itself, the following recommendations are arrived.

- Only two spots are recommended for the parts of surface contact area up to 10,000 Sq-mm.

- Sufficiently, three spots are recommended for parts of surface contact area between 10,000 Sq-mm and 1,00,000 Sq-mm.

6 This study is limited with the part size range of 9,900 sq-mm (minimum) and 105,030 sq-mm (maximum). There is a further scope to work in future with larger sizes and complex shaped parts.

From this study results, it is observed that minimum two spots and maximum three spots are recommended to assign between the two parts. Accordingly a guideline is provided with surface area calculation to distribute the spots in the geometry stations for various sizes and surface contact parts. This is a simple but very appropriate method to distribute the spots in the geometry station. As discussed above, lesser spot distribution will lead to inferior quality and excess spot distribution will lead to lesser productivity. The body shop process planner can follow the given methodology of spot distribution for the entire body shop sub-assembly stations and thereby, he can ensure the BIW geometry set through integrated product and process planning.

References


