CHAPTER 1

INTRODUCTION

1.1 AUTOMOTIVE BODY ENGINEERING

Automobile car body is a rigid shell which accommodates all the functional and aesthetic parts of a vehicle. Body-on-chassis and Uni-body are the two major body types used in automobile. Typically, sheet metal components of various steel grades and thicknesses are used to build a rigid body structure. Aluminum and composites are also used to make bodies with limited quantity requirements and for special purposes.

The basic body structure of an automobile ranging from 200 to 400 parts, according to the model, is fabricated by spot welding method. The range of spot weld in completing body structure varies from 3000 to 6000 spots. Figure 1.1 Shows the comparison of parts vs. spots distribution of typical automobile bodies.

![Figure 1.1 Number of parts vs. Number of spots comparison](image)
Body components and joineries are designed according to the styling surface of the vehicle and the product designer assigns appropriate number of spot welds to the welding joineries, according to the Computer Aided Engineering (CAE) simulation outcome. A typical body structure of a uni-body design is represented in figure 1.2.

![Figure 1.2 Automotive body structure](image)

Fabrication of automotive body is crucial because ultimately it freezes the safety, convenience and comfort. Reduction of product development lead time and control over product cost are the major challenges in body engineering [1].

Body engineering department has six main areas of focus; sheet metal, body metal, fenders, hood, radiators and general hardware [2]. Body engineering is responsible for designing complete body structure with weld spots, sealants and hardware details. Spot welds are generated in a spot cloud module and populated in the body structure with spot weld annotations.

Process planners extract the body design and spot cloud data for process planning from a design software platform (e.g. CATIA), and distribute the spot welds in various weld stations in a body shop layout. This virtual...
plan is implemented in the physical body shop by the process engineers. Simultaneous engineering, quick design change, and seamless processes from the pre-styling idea development stage to the manufacturing stage are very critical in product development [3]. Figure 1.3 represents the typical spot weld cloud of an automotive body and figure 1.4 represents the body structure with the spot weld cloud.

Figure 1.3 Automotive body spot weld cloud

Figure 1.4 Automotive body structure with spot weld cloud
1.2 AUTOMOTIVE BODY MANUFACTURING

A typical body structure consists of three major assemblies, figure 1.5

1) Under body (or) Floor complete
2) Upper body (or) Side complete
3) Closure (doors, hood and tail gate) assemblies

Basic structural knowledge of an automobile body is key for a body design engineer to achieve the major product development targets of cost, weight and performance [4].

The shop floor in which the bodies are built or assembled, is known as a body shop or weld shop. In the body shops, around 200 components get assembled in different welding stations or stages, classified as geometry stations and re-spot stations. Body manufacturing shops are mainly classified into three types; automated, semi-automated, and manual types. Automated body shops require a larger space in the plant layout and the investment is higher compared to the other two types. The reduction in investment and life cycle operating costs can be achieved through implementation of modular concepts in body manufacturing systems [5].

Figure 1.5 Body assembly family tree
1.3 AUTOMOTIVE BODY QUALITY

1.3.1 Introduction

In the current automobile trend, quality has emerged as one of the major priorities for all the manufacturers across the globe [6]. Focus on quality has extended the need for optimization in processes and functions that are both directly and indirectly related to the manufacturing processes and design specifications [7]. In BIW, the quality of the car body is said to be achieved, when the specification demanded by design is fully satisfied. The purpose of quality control is to assure and maintain the characteristics of the car body within the acceptable quality level. The success of automobile companies is decided with the fulfillment of customer perceived quality [8].

![Figure 1.6 Elements of BIW quality control](image)

Figure 1.6 Elements of BIW quality control

Figure 1.6 represents the four major elements that need to be planned and controlled for achieving the specified BIW quality.

1. Dimensional Quality
2. Weld Quality
3. Fit & Finish
4. Sealing & Rust Prevention
All four elements are defined in the product design phase and the roles of the process design and manufacturing are vital in achieving the four quality elements in continuous production.

Dimensional quality is directly linked with the other elements such as fit & finish and weld integrity. Dimensional control of a part or sub assembly begins with GD&T calculations (Geometric Dimensioning & Tolerancing), which is one of the key activity in product design. The assembly sequence and tolerancing for each part is derived from GD&T calculations. The derived calculation will be incorporated in the product design and a controlled process is required for achieving the same in manufacturing. A dynamic and modern engineering approach will automatically reduce cost and assures the highest possible on time product quality. Exact dimensional management is the effective method of quality assurance [9].

Weld quality is another critical element to be planned and controlled to achieve stiffness and reliability of the vehicle. Spot weld integrity is highly significant as it is directly associated with the safety of the passengers. Failure of critical spot welds in a vehicle may lead to major failures of functions, which may lead to breakdown or severe damage of the vehicle, causing bodily harm to the occupants.

1.3.2 Body Quality Assurance System

To manufacture a qualitative BIW, the quality function of a body shop must have a defined and structured philosophy of work. It is necessary to adopt an appropriate defect deduction system in the shop floor for filtering defective assemblies. The level of periodic quality assurance of production processes and verification of reliability in the operations are critical to maintain quality [10]. A typical quality control system of a body shop employs the following quality control measures.
Body quality inspection plan is given in figure 1.7.

![Body quality inspection plan](image)

**Figure 1.7 Body quality inspection plan**

### 1.3.3 Panel Quality Inspection

Panel quality plays a vital role in automotive body manufacturing processes [11]. Quality of sheet metal panels are confirmed through visual and dimensional measurements. Checking Fixture (CF) is a quality inspection gauge used to confirm individual panel dimensions. A checking fixture has surface contours as per the component drawing specification to check the dimensional quality of a component or assembly. Checking fixtures are available for all press formed panels used in a body shop.

Checking fixture is used to inspect:

- Panel trim line & break line conditions
- Tooling & part mounting holes position
- Panel profile to specification
A typical checking fixture of a fender panel is represented in figure 1.8.

Figure 1.8 Checking fixture of a fender panel

1.3.4 Sub-Assembly Inspection Process

Inspection Fixture (IF) is a quality gauge used to confirm assembly condition of welded (or) bolted panels. An inspection fixture replicates the tooling pins of a welding fixture, thus part seating in inspection fixture ensures (or) predicts the proper seating of parts in the welding fixture. Inspection figure of a door assembly is given in figure 1.9.

Figure 1.9 Inspection fixture of a door assembly
Inspection fixtures play a crucial role for consistent monitoring of door hinge position, gap & flushness of door assembly. Sub-assembly variation levels can be controlled through optimized datum-shifts between assembly stations, measurement gauges and assembly process [12].

A BIW inspection fixture is used to replicate the main framer condition, to confirm the matching of the upper body with the under body. The main framer is the most crucial welding station in a body shop, which is used to assemble all the major assemblies such as under body, side assemblies, roof panel, roof headers and rails to form a body structure, figure 1.10.

Inspection fixture is used to inspect;

- Dimensional quality of an assembly (Gap & Flush)
- Mounting locations of closure parts
- Parts seating condition in welding fixture

![Figure 1.10 BIW main framing station](image)

**Figure 1.10 BIW main framing station**

1.3.5 **BIW structure dimensional inspection using CMM**

Dimensional quality is a measure of conformance of the actual with the specification. In the automotive body assembly process, dimensional
control and its maintenance is critical to the product quality [13]. Dimensional integrity of every part, every material, every tool and every process contribute to the overall build quality [14].

Dimensional co-ordinates of a vehicle are represented by XYZ, figure 1.11.

- X – Longitudinal direction
- Y – Transverse direction
- Z – Height direction

“X & Z” Coordinate references

“Y” Coordinate references

Figure 1.11 Vehicle co-ordinate system
Three-dimensional (XYZ) measurements of a body structure are confirmed using a Co-ordinate Measuring Machine (CMM). Position of major mounting points and surface points with respect to vehicle co-ordinates are confirmed through CMM Inspection. A Coordinate Measuring Machine (CMM) is a device used for measuring the physical geometrical characteristics of an object with respect to Computer Aided Design (CAD) data of an object. The object can be a small part or a large BIW. CMM machines are broadly classified into two types:

1. Column mounted controlled movement CMM machine
2. Portable CMM machine

BIW CMM inspection is used to measure and analyze the below parameters

- Three-Dimensional accuracy of the BIW (XYZ positions)
- Interior / Exterior Fit & Finish
- Fitment of functional parts

Improving the range in measurement with latest technology is critical to achieve high precision quality [15].

1.3.6 Body Building Process

1.3.6.1 Types of sheet metal joining

The complexity of new car body calls for the necessity of a concurrent engineering approach. The best properties can only be achieved by an integrated process of materials choice, body concept and joining methods [16].

The familiar methods for sheet metal joining are,

1. Resistance spot welding
2. Metal Inert Gas (MIG) Welding
3. Laser welding
4. Riveting
5. Adhesive bonding

However, resistance spot welding is the most widely used joinery process across the globe for mass manufacturing of automotive bodies as it holds significant benefits in the automobile context compared to the other processes.

The salient merits of resistance spot welding (RSW),

1. Most suitable for mass production compared to any other technique
2. Low capital investment and less operation cost
3. Moderate speed and environmentally friendly
4. Quality of the weld strength is high as the base metals are fused after melting
5. Safe process and doesn’t require any special control system
6. Requires moderate skill for weld gun operation
7. Welding equipment is compatible with both manual and robotic welding processes
8. Process time is very short compared to other techniques
Body sheet metals can be joined in different methods, figure 1.12.

![Figure 1.12 Sheet metal joining techniques](image)

1.3.6.2 *Resistance spot welding*

In a car body, multiple types of high strength steels are used to form a rigid structure. The sheet metal panels are typically joined by resistance spot welding [17]. The strength of body assembly parts is mainly dependent on the strength of the spot-welded joints. The weld quality of the body is confirmed by destructive and non-destructive methods. Compared to other welding processes, the resistance spot welding process has a low process cost and requires a lower operator skill. The process is faster and has a better weld accessibility compared to other welding methodologies. This makes the resistance spot welding (RSW) process is ideal for robot automatization and therefore makes it an idyllic choice for automotive production [18].
Resistance spot welding is an application of Joule’s first law of heating. The heat generated due to the resistance of a conductive workpiece to the flow of current is a function of three parameters; weld current, conductive workpiece resistance and the time duration of flow of current. Spot welding illustration of a sheet metal combination is given in figure 1.13.

Joule’s first law of heating is represented as $H=I^2 RT$.

Where,

$H$ = Heat,

$I$ = weld current,

$R$ = conductive workpiece resistance

$T$ = Time duration of flow of current.
A resistance spot weld joint is typically designed such that a welded joint has a shear force acting on it, when the sheets are subjected to tension or compression.

Inspection of a spot weld is being done with two major methods, figure 1.14.

1) Non-destructive testing

2) Destructive testing

![Figure 1.14 Spot weld inspection methods](image)

**1.3.6.3 Non – destructive inspection**

Non-destructive inspection of spot welds is carried out without any deformation of the sheet metals to find ‘Pass’ or ‘Fail’ of the welding by examining the surface of the welded spot. This way of inspection is done by visual evaluation, dye penetrants and ultrasonic wave echo inspection.
1.3.6.4 Destructive inspection

Chisel test

This is a method to confirm ‘Accepted’ or ‘Not Accepted’ spot welds by using chisel and hammer, figure 1.15.

Chisel test is used to find the strength of a spot weld between the two panels and the test is performed manually.

![Chisel test diagram]

Figure 1.15 Spot weld chisel test

Teardown:

Teardown is one of the common methods employed to find the spot weld strength in a BIW assembly.
Figure 1.16 represents the process of tear down spreader tool is used to open the welded joineries of the sheet metals with externally applied force.

![Spot weld tear down spreader](image)

**Figure 1.16 Spot weld tear down spreader**

### 1.4 INTEGRATED DESIGN AND MANUFACTURING - IDAM

In automotive industry, product and process design activities are integrated and development proceeds simultaneously to deliver quality products. Product and process designers work together to materialize the virtual final design of the product, with quality and easy manufacturability. Body design release activity happens with the concurrence of the manufacturing engineering team to produce quality product with better manufacturability.

BIW geometry co-ordinates of each part are defined by the product designer in the design phase and it is the responsibility of process designer to plan appropriate processes to set geometry between the parts in the physical build. Spot distribution between the welding stations is a process planning activity which is simultaneously engineered during the product design stage.
The given flow chart of the integrated product and process elaborates the function of IDAM, figure 1.17.

![Flow chart of integrated product and process design]

Figure 1.17 Flow chart of integrated product and process design

1.5 NEED FOR QUALITY AND PRODUCTIVITY IMPROVEMENT

Quality and productivity are the two crucial elements of any manufacturing facility, and continuous improvement of both the elements is vital to the growth of any organization. Shanin has studied and highlighted the role of quality in improving the productivity of operations. He determined a strong correlation between quality and productivity [19]. Manufacturing
systems and quality management practices are found to be critical in maintaining competitive advantages [20].

Customer demands, globalization, shorten product development time, cost cutting are the unprecedented challenges for the manufacturing industry [21]. In the automotive industry, well organized and robust manufacturing processes are required to achieve craftsmanship targets [22]. Optimization of fixture design by reducing non-standard units in the weld fixtures is critical to reduce the time for designing the fixture and reducing the development cost [23]. Linking concept design with manufacturing methodologies is essential for leaner design and leaner production [24]. Stability in product and process equipment is critical in reducing the quality variations in a car body [25]. Optimization of fixture layout in a body shop has a significant positive impact on the reduction of manufacturing costs [26].

Lean manufacturing concepts emphasize the reduction of process times in manufacturing facilities to optimize the resources. Mothersell has studied the brownfield conversion from mass manufacturing to lean production in a large automotive company. He has explained the coherent transformational model for converting the brownfield facility into a lean production facility.

The following key technical components were considered in the lean conversion study,

1) Changes in the assembly layout

2) Changes in TAKT time and jobs per hour (JPH), [27].

Improvements or innovations for improving quality and productivity happen independently, without any mutual negative impact. In some cases, both must rise together and this study is one among them.
1.6 BODY SHOP WELDING FIXTURES

Geometry stations are designed and manufactured to locate the parts and weld the key spots that set the geometry of the assembly. Geometry fixture is a fixture that locates precisely, all the parts that are added in that fixture and ensures that the geometry is set along with the key spots welded in that fixture. Figure 1.18 represents the construction of a typical geometry welding fixture. The assembled parts become a single piece after the geometry station; which can be moved further in the system without being concerned about the dimensional distortions. This means that all the defined nominals of the two parts are fixed within the allowable defined tolerance limits.

![Geometry welding fixture](image)

Figure 1.18 Geometry welding fixture

Re-spot stations are designed to complete the rest of the spots defined by the Product designer. Re-spot welding fixture is just a workholding device or support device that holds the parts output from a geometry fixture. No additional parts are added in this fixture and no additional units for parts location are needed in these fixtures.
Figure 1.19 represents the typical re-spot fixture of a body shop.

Spot allocation among the stations is a critical process planning activity; improper planning of spot allocation will impact quality and productivity of the shop. Allocation of fewer spots in geometry station will lead to quality deterioration and allocation of higher spots than the required spots will lead to productivity loss.

1.7 GLOBAL TREND OF GEOMETRY AND RESPOT STATIONS

Global trend of geometry and re-spot distribution of various body shops has been studied with the data collected from weld line builders located in South Korea. Weld line builders deal with various automotive manufacturers of the globe and are an appropriate source for getting authentic data of various weld shop fixture distribution percentages.
Geometry, and re-spot fixture quantity and JPH details are obtained to understand the global trend. The weld line builders have shared the requested details without disclosing the manufacturer details. However, percentage of fixtures is considered as the focus of this study and not the manufacturer. The models of United States, Europe and Asia are considered to obtain generalized global trend in this study. The geometry and re-spot fixture percentage is studied with the perspective of automation level used by the various automakers.

**Figure 1.20** Global trend of geometry & re-spot stations for automated lines

Figure 1.20 shows the global trend in distribution of geometry and re-spot stations for 100% automated lines. The 100% automated lines fixture details are denoted from X1 to X6. The global trend in distribution of welding stations in 100% automated lines clearly indicates that the geometry stations percentages are ranging between 31% and 45%. The re-spot percentage of the models are ranging between 55% and 69%. The percentages of geometry stations of the same capacity lines are designed with a 14% difference. This trend also indicates that the geometry stations percentage is low compared to re-spot stations percentages.
Figure 1.21 Global trend of geometry & re-Spot Stations for semi-automated lines

Figure 1.21 represents the global trend of geometry and re-spot weld percentages of semi-automated and manual lines. The models are denoted from Y1 to Y6 and plotted against the automation percentage. The automation levels of these models ranging from 10% to 90%. The observation from the trend chart clearly indicate the influence of automation in selection of geometry and re-spot stations. The semi-automated/manual lines are typically dedicated to specific models. Sharing of semi-automated/manual lines by similar platform models is very rare. In both cases, semi-automated and manual lines have dedicated geometry and re-spot stations for each model. Automated lines are typically multi model lines with changeover geometry fixtures and shared re-spot fixtures among the models across a wider range. This is one of the major differences between automated and semi-automated lines.

The trend of semi-automated and manual lines, given in figure 1.21, indicates the following key points.
1) Geometry stations percentage is lower when the automation level is above 40%.

2) In the given weld lines with over 40% automation, geometry stations percentage ranges from 33% to 45%. A difference of 12% observed on weld lines with same capacity models with almost equal automation percentage.

3) The percentage of geometry stations is almost double in lines with automation below 40%, compared to the lines with above 40% of automation. This drastic increase is the result of weld lines being used predominantly for dedicated models rather than multiple models.

4) The geometry stations percentages in weld lines with less than 40% automation lines are ranging between 53% and 82%. A difference of 29% observed on weld lines with models of same capacity.

1.8 SUMMARY

The geometry stations percentage varies from 31% to 82% across weld lines of different automation levels. The difference in geometry stations percentage between semi-automated/manual lines could be related to the automation levels of the weld lines. The difference in weld lines with similar automation levels with same capacity shows that the difference is a result of lack of optimization.

The variation percentage of same capacity weld lines are summarized below.

1) Variation in 100% automated lines – 14%

2) Variation in 40% to 90% semi-automated lines – 12%

3) Variation in below 40% semi-auto / manual lines - 29%
Higher the percentage of geometry stations in a body shop, lower will be the productivity of the shop. It is observed that the cycle time of a geometry station is considerably higher than a re-spot station and this is one of the major focus area for productivity improvement. Addressing this issue will lead to a significant improvement in the productivity of a body shop.

Based on studies, it is observed that the time taken to weld the same spot is around 35% higher in a geometry station than when done in a re-spot station.

The designation of minimum spot welds to set the geometry in the geometry station must be done with a scientific approach. This ensures that there is no negative impact such as issues in dimensional quality. Spot welds required to set the geometry is one of the most critical factors which affect dimensional integrity. Lower the number of spot welds welded than the minimum required quantity, higher will be the probability of dimensional variation in the assembled parts.

Productivity of a re-spot station is comparatively higher than that of a geometry station because of the difference in process time, i.e., the time taken to complete one spot weld in a geometry station is higher compared to a re-spot station. In a manual geometry station as considered in this case study, the average time taken to weld a spot is 7 seconds, whereas in the re-spot station it takes only 4.5 seconds to complete a spot weld. This is because of the complexity of the geometry station as there are more fixture units; constraining the weld gun access in those stations. Comparatively, a re-spot station is less complex due to fewer number of fixture units. It must be noted that there is a mean difference of 2.5 seconds per spot weld; a 35% reduction of the weld time is possible to achieve irrespective of manual or automated processes.

In this study, this issue is addressed through a scientific approach by distributing the minimum required spots in any geometry station. This
enables assembly of more number of parts at the same geometry station. This paves way for welding maximum number of spot welds at re-spot stations. This will result in improved productivity, irrespective of the automation influence on number of stations.