DESIGN AND IMPLEMENTATION OF MECHANICAL POKA-YOKE SYSTEM USING PROGRAMMABLE LOGIC CONTROLLER

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Abstract- In this work company is having a assembly problem of wrong fitment of “Nut Plate” or “Bracket” on Sill. This Sill is spot welded with assembly of front floor of Bolero vehicle. Hence wrong assembly of front floor, this floor is assembled with body of Bolero vehicle. Due to wrong assembly of front floor in body of Bolero vehicle, losses in terms of cost, time, production and transportation are high so it is a critic issue. To solve this assembly issue we use a tool called as Poka-Yoke. In assembly lines of vehicle, the idea of Poka-Yoke implementation is a necessary work from decades. Although the different Poka-Yokes are implemented in assembly lines, the principle of flow production as central element of Lean Production have not often been transferred successfully to assembly areas yet. This is because continuously rising of complexity of product design. We designed and implemented Poka-Yoke successfully using Programmable Logic Controller for Bolero front floor assembly.

Keywords- Assembly, Front floor, Nut plate, Poka-Yoke, Sill

I. INTRODUCTION

In this work company’s Bolero TCF (Trim-Chassis-Final) shop assembly line having a problem of front floor of Bolero Vehicle. In TCF shop number of activities of assembly of vehicle taking place such as all internal and external mountings in body of vehicle like seats, air conditioning, cables, window’s side and back glasses, in front of driver glass, head lamps, tail lamps, mirror etc. Chassis of vehicle is assembled with gears, steering, axles, wheels, suspension system, brakes etc.

After that body of vehicle is lifted with the help of overhanging tackle from one assembly line and mating on a chassis of another line so here marriage of chassis and body of vehicle is taking place. But sometimes the mating of chassis and body are not taking place.

This is a stage where problem is identified. Because of this TCF assembly line is stopped and so many losses occurred. After identification and analysis of problem it is decided to solve this problem using Poka-Yoke tool. In body shop, body of vehicle is made up from assemblies of underbody (front floor, centre floor, rear floor), side body (front door, rear door, back door), roof, front etc. After completion of body it is passed through paint shop and then TCF shop.

These bodies are having a different variant. For example – Variants of Bolero are Bolero SLX, Bolero DI, Bolero Longer and P-105. Wrong assembly of front floor in body of Bolero vehicle is because of its two variants namely categorized as 1) Regular Bolero 2) P-105 (Bolero Maxi truck). Also bodies of these two variants subassemblies are also having a product design changes. For example - Front floor of Bolero vehicle.

II. POKA-YOKE

It was a Japanese manufacturing engineer named Shigeo Shingo who developed the concept that revolutionized the quality profession in Japan. Originally called “fool proofing” and later changed to “mistake proofing” or “error proofing” The result is an operation that wastes less energy, time and resources doing things wrong in the future. The main purpose of Poka-Yoke is to reduce defects from mistakes using the simplest and lowest-cost techniques possible. Poka-Yoke is implemented by using simple objects like fixtures, jigs, gadgets, warning devices or paper systems to prevent people from making mistakes—even if they try to. These objects, known as Poka-Yoke devices, are usually used to stop the manufacturing process and alert the operator if something is about to go wrong.

GENERAL STEPS OF POKA-YOKE
i) Problem Identification
ii) Observation
iii) Brain Storming for Idea generation and its selection
iv) Best idea implementation

Let’s see above steps one by one

i) Problem Identification:
As mentioned earlier in the introduction that identification of problem is now showing with the help of block diagram in Fig: 1

It is showing that a general vehicle manufacturing process in which Body of Bolero Vehicle is made from body shop. This body is then passed through the paint shop with the help of conveyers where body is painted with colors. This body is send to TCF shop. In TCF shop at marriage station problem is identified.

![Fig: 1 General Vehicle Manufacturing Process](image)

ii) Observation:
Front floor assembly on a fixture is made up of stages wise. In stage 1, sills are locating on a first fixture and took a spot for the formation of a skeleton after that floor panel is kept on it and took a spot with the skeleton of sills only for geometry formation. In stage 2, it is known as re-spotting stage where remaining spots are taken to strengthen the front floor. Fig: 2 is showing that front floor of Bolero P-105, in this floor, Sill which is highlighted with number (1) is known as “Critical Sill” (only for simplicity) because problem is observed in this sill and its mirror sill along vertical direction.

![Fig: 2 Front Floor of P-105](image)

In Fig 2.1, it shows “Nut Plate” is present on a Critical Sill, true position of “Nut Plate” is on a hole which highlighted in Fig: 2.2 with green arrow “A”. If position of “Nut Plate” is shifted on a hole which is highlighted in Fig: 2.2 with red arrow “B” then it will be wrong position of “Nut Plate”. This is a mistake has done by operator.

In the front floor of Bolero P-105, Critical Sill is present with “Nut Plate” on its true position which is shown in Fig: 2.1 where as in the front floor of Regular Bolero, “Nut Plate” is not required which is shown in Fig: 2.2.

![Fig: 2.1 Nut plate is present on a critical Sill](image)

![Fig: 2.2 Nut Plate is absent on a Critical Sill](image)

iii) Brain Storming for Idea generation and its selection

The following ideas are generated

- Manual inspection of front floor before under body assembly
- Manual inspection before assembly of front floor
- Separate front floor assembly fixture for separate model
- Do Poka-Yoke on a 1st stage front floor existing assembly fixture.

From all the above idea it is observed that doing Poka-Yoke is feasible because other ideas are time consuming, more expensive and most important there are chances of mistakes and hence defective assemblies.

III. DESIGN AND MODELING USING CATIA-V5 SOFTWARE.

As mentioned earlier above in step two (Observation) of Poka-Yoke in that we explain about assembly stages of front floor on a fixture. Fig: 3.1 is showing stage-1 front floor assembly fixture.
We made 3-D model of fixture using 2-D data on which product data of Bolero’s floor sills is imported. We can see that sills are located on locating pins and it formed the skeleton like structure. For clamping of these sills including critical sill toggle clamps are used. We design and model mechanical elements of Poka-Yoke system and assembled on a fixture at a position of critical sill’s toggle clamp, its LH and RH side as shown in Fig: 3.1.

Fig: 3.1 Poka-Yoke Implemented on a Fixture

Fig: 3.2 Enlarge View of Poka-Yoke

Fig: 3.2 showing enlarge view of Poka-Yoke on a fixture. In that assembly of 3-D model of Poka-yoke highlighted with 1 to 9 numbers. (1) Pneumatic Cylinder, (2) Piston Rod, (3) Clevis, (4) Clamp Arm, (5) Handle, (6) Pin-Spring and Sensor mechanism, (7) Clamping Mylar, (8) Catch and (9) Pivot Point. Clamp arm’s one end is connected to “Pin-Spring-Sensor” mechanism and other end is connected to piston rod’s end of cylinder with the help of clevis. Pneumatic cylinder is double acting. Position of arm on a critical sill is in clamped condition. Arm is opened and closed by using pneumatic cylinder. In this way we did design, modeling and kinematic simulation of mechanical elements of Poka-Yoke system.

IV. WORKING OF POKA-YOKE

Cut section of “Spring-Pin-Sensor mechanism” shown in Fig:4, numbers from 1 to 8 are showing cut section of sub elements of mechanism. (1) Pin-1, (2) Pin-2, (3) Spring, (4) Clamp Arm, (5) Handle, (6) Pin-Spring and Sensor mechanism, (7) Clamping Mylar, (8) Catch and (9) Pivot Point. Clamp arm’s one end is connected to “Pin-Spring-Sensor” mechanism and other end is connected to piston rod’s end of cylinder with the help of clevis. Pneumatic cylinder is double acting. Position of arm on a critical sill is in clamped condition. Arm is opened and closed by using pneumatic cylinder. In this way we did design, modeling and kinematic simulation of mechanical elements of Poka-Yoke system.

In Fig:3.2 and Fig:4, arm is in clamping condition on critical sill. At the time of clamping pin-1’s bottom end touches the nut plate therefore pin-1 will lift upward, on pin-1’s top face sensing plate is attached by screw and another end of sensing plate face is above the top surface of proximity sensor-1 that is sensing plate moved upward beyond the sensing region along with pin-1.

At the same time below the pin-2 instead “Nut Plate” there is a hole on critical sill whose diameter is more than pin diameter therefore pin will easily goes into hole. Therefore there is no lifting of pin-2 and sensing plate, as a result of this sensing plate is in influence of proximity sensor-2. From proximity sensor-1 and proximity sensor-2 signals send to PLC (Programable Logic Contoller). Logic chart of PLC for Poka-Yoke is shown below in Table:1. From Table-1 it is cleared that after clamping for regular Bolero all 4 Pins should within the range of proximity sensor and for Bolero P-105 pin-2 and pin-3 should within the range of proximity sensor and pin-1 and pin-4 should beyond the range of proximity sensor.
If "Nut Plate" is shifted to another location then after clamping “Pin-Spring- Sensor mechanism” gives signal to PLC and there will be alarm, by using pneumatic valve (5/3 valve) critical sill is unclamp and vice versa. operator will remove wrong sill and place correct sill and correct the assembly then operator will reset alarm and process again start. In this way correct location of “Nut Plate” is identified and wrong assembly will be avoided. This arrangement is for LH side and it’s mirror arrangement has done RH side as shown in Fig: 3.1.

V. CALCULATION OF CYLINDER DIAMETER

Material applied on modeling geometry of Clamp Arm is mild steel therefore value of mass has taken from modeling software. Fig: 5 is line diagram of arm.

M1= Total mass on Clamp Arm = 7.84 Kg
X1=Distance between pivot point and clamp arm sensor mechanism end = 445mm = 0.445m
X2= Distance between pivot point and another end of clamp arm = 75 = 0.075m
M2= mass to be pull by cylinder = ?

\[
\begin{align*}
M2 &= \frac{X1}{X2} \\
&= \frac{7.84 \times 0.445}{0.075} \\
&= 51.176 \\
\end{align*}
\]

We know that from a law of similar triangle

\[
M1 \times X1 = M2 \times X2
\]

Consider, Factor of Safety (F.S.) = 2,

\[
M2 = 46.52 \times 2 = 93.04 \text{ Kg}
\]

\[
\text{Cylinder Force (F) required to pull mass M2 is,}
\]

\[
\text{Force} = \text{Mass} \times \text{Gravity} = 93.04 \times 9.81 = 912.72 \text{ N}
\]

Also we know that

\[
\text{Pressure} = \frac{\text{Force}}{\text{Area}}
\]

\[
\pi R^2 = \frac{F}{P}
\]

\[
3.1416 \times R^2 = \frac{912.72}{5 \times 10^5}
\]

\[
R = 0.02410 \text{ meter}
\]

\[
D = 2R = 2 \times 0.02410 = 0.04821 \text{ meter},
\]

48.21 mm = 50 mm.

As per std. cylinder diameter in the nearer range of 50mm is 63mm therefore we used 63mm diameter cylinder.

VI. ANALYSIS OF CLAMP ARM

In this phase we have done analysis of clamp arm in Ansys-12 software, analysis of clamp arm carried in static condition, result of analysis used for finding deflection of arm. Suitable data of modeling of clamp arm imported in Ansys-12 and analyzed from structural analysis by applying boundary conditions.

VII. IMPLEMENTATION OF POKA-YOKE

Results of analysis are safe after concluding this we generated detail drawings of mechanical elements of Poka-Yoke system, manufactured and implemented on a front floor 1st stage assembly fixture which is shown in Fig: 7.1, 1) “Spring-Pin-Sensor mechanism”, 2) Proximity Sensor, 3) Nut Plate on Critical Sill and 4) Clamp Arm. Simultaneously other requirement like pneumatic connections, PLC panel and pneumatic valves assembled. Fig: 7.2 showing
The PLC panel on which various indicators are shown at bottom end left faint yellow switch is of control ON and right side button is of buzzer reset, second last row is in 4 green light indicators which are of proximity sensor indicator lights. Third last row is showing 3 indicators among which green light is of model ok, yellow light is of model not ok and red light is of buzzer. Top red light is of mains ON means PLC panel is in ready condition.

**RESULT AND DISCUSSION**

1. Results of analysis are showing that stresses and deflection produced in the Arm is much smaller therefore design of arm is safe.
2. Kinematic simulation of mechanical elements did in Catia V5 software is practically worked on a front floor assembly fixture during trail of Poka-Yoke.
3. We did automation to detect wrong assembly therefore any kind of operator can work to do assembly of front floor.
4. In this way we

4.1) We identified root cause of wrong assembly,
4.2) We 100% eliminated wrong assembly of front floor,
4.3) Rework time or scrap of front floor of Bolero vehicle 100% eliminated.
4.4) Increased the production rate.

**CONCLUSION**

From results and discussion we concluded that though there are continuous changes in product design, we can arrest the defect by implementing Poka-Yokes.

**REFERENCES**


