Redesign of Test Station Equipment and Methodology to Reduce Human Factor Errors in Time Calculation and Test Conditions

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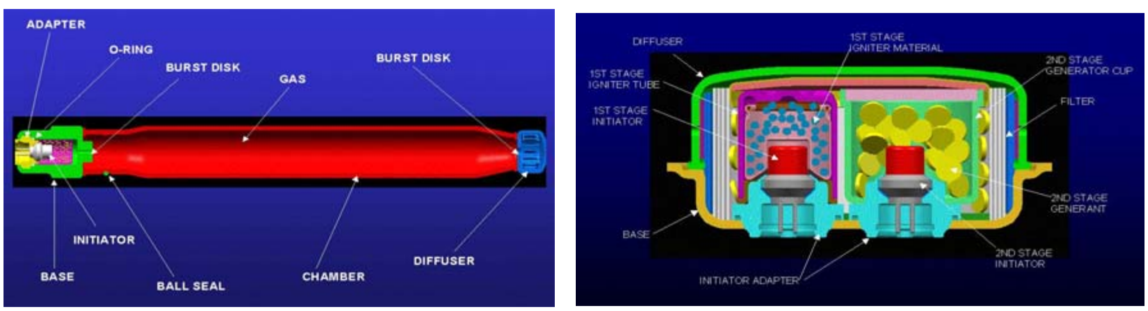
Introduction

The airbags in an automobile are part of the overall safety system, the failure of which can cost people's lives. As such, airbag modules are subject to tighter reliability and quality control inspections than is typically encountered in the automotive component industry. Industry standards have been developed for the testing of airbag modules used for United States production intent vehicles. Such standards are administered through organizations such as the Society of Automotive Engineers (SAE) and the United States Council for Automotive Research (USCAR).

The airbag inflator is the mechanical device which produces the gas that fills the bag. Airbag inflators are divided into two separate technologies: pyrotechnic and stored gas. The pyrotechnic inflator burns chemicals similar to a rocket propellant in order to produce gas. This type of airbag is utilized for the driver and passenger protection. A stored gas inflator is little more than a compressed gas cylinder which opens to fill an airbag with cold gas. Stored gas inflators are used for side impact airbags, knee bolsters, and rollover curtains. Simplified schematics for airbag inflators are shown in Figure 1.



Stored Gas Inflator Pyrotechnic Inflator

Figure 1: Airbag Inflators

Inflators are required to produce a certain molar output of gas. The time in which the gas is delivered to an airbag is the determining factor for the bag's proper deployment. In order to measure this, inflators are ignited in a closed tank of a certain volume, typically 60 or 100 liters. Electronic transducers measure the pressure inside the tank, recording ten thousand data points per second. Customer specifications require certain levels of pressure at times such as ten to one hundred milliseconds following ignition. The pressure curves allow the actual bag to be designed with sufficient strength to stand up during deployment. The latest generation of inflators can produce high or low output that can be selected based upon the speed of crash, as well as the seat occupant weight and position.

Qualifications of airbag inflators are done in a manner similar to qualify ammunition lots or batches of rocket motors. The true testing of performance can only be done destructively, and are performed using a Lot Acceptance Test (LAT). LAT's are performed for each eight hour production shift, with three inflators tested each at high temperature, ambient, and at low temperature. The exact times for conditioning and the temperatures for testing have varied by the car making customer, but typically run from -40 to +85 degrees Celsius.

Customer Corrective Action Request

In an audit of our testing procedures, a car maker customer found several errors with regard to our Lot Acceptance Tests. Inflators were found to have been conditioned at the incorrect time prior to firing. In addition, there was disagreement as to what the required temperature needed to be in order to meet USCAR and customer requirements. A Corrective Action Request was implemented against the company, and a team was formed to address concerns regarding Lot Acceptance Tests.

Ford Global 8D Problem Solving Approach

Although the company sells to almost every global automobile manufacturer, Autoliv North America has chosen to utilize the Ford Global 8D problem solving approach. The eight "Disciplines" are as follows:

1. Establish the team
2. Describe the problem
3. Develop interim containment actions
4. Define and verify root cause and escape point
5. Choose and verify permanent corrective actions
6. Implement and validate permanent corrective actions
7. Prevent recurrence
8. Recognize team and individual contributions

Each of these activities will be covered separately below:

Establish the Team:

A cross functional team was formed to investigate the issues of LAT conditioning, and included members from the Quality, Engineering, and Operations departments. On the team were members of management, non-exempt technicians, and two hourly maintenance workers. It has been found in the past that cross-functional teams will give the best answers for problem solving since issues will be approached from both theoretical and practical sides.

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Describe the Problem:

This step is for providing adequate definition of the problem. The cause and effect diagrams are commonly used in this phase of the methodology. The key aspect of this step is to separate symptoms from the underlying problem. For this investigation, the problem definition was formalized as: “The conditioning step for Lot Acceptance Tests is subject to errors in both time and temperature prior to firing.”

Develop Interim Containment Actions:

The lots of airbag inflators in which the audit findings concerned had already been shipped to the module makers and installed in cars. The customer determined that no retrieval of the affected airbags was warranted inasmuch as testing was conducted and passed, and the nature of the procedural deviation was minor.

For an interim corrective action, it was decided that the testing supervisor would review each shift’s testing to ensure that no additional errors in testing would take place until permanent corrective actions could be conceived and implemented.

Define and verify Root Cause and Escape Point:

A thorough analysis by the team was conducted, utilizing the Ishikawa diagram, as well as a specialized check list utilized in the 8D training manual. As a result of the investigation, the following observations were noted regarding Lot Acceptance Testing in our company:

1. Errors in conditioning were found to be fairly frequent in the company, beyond what had been found by our customer.

2. Errors were not limited to a single operator, but to operators at multiple locations, on multiple shifts, and with both experienced and novice employees.

3. Errors were made with relation to both temperature and time duration in the conditioning “ovens”.

4. The time for conditioning an inflator varied from one to two hours. These times were determined using thermocouples inside units and tracking the time to reach thermal stability. Smaller inflators required only one hour of time in a conditioning oven. For larger inflators the time could be 90 or 120 minutes.

5. Conditioning times were hand calculated by technicians. The oven loading time was recorded on the test sheet, and the time that the test was performed was then listed on the sheet.

6. The temperature for conditioning had many variations. The cold testing could be performed at -45, -40, and -35°C. Hot testing could occur at 80, 85 or 90°C. Each of these temperatures required maintenance of a dedicated oven.

Based upon these observations, two root causes for potential errors were found to exist:

- Reliance upon operator calculations for conditioning duration will result in errors.

- Non-standardization of conditioning times and temperatures will result in unacceptable error rates.

Choose and verify Permanent Corrective Actions:

The team recognized that corrective actions for the temperature of the ovens would not be the same as the corrective action for the time in the ovens for conditioning. It was decided to observe how this activity was handled in other locations using a benchmarking activity. Benchmarking is a way of capturing best practices by visiting or researching other companies performing a function, to see what lessons can be learned.

Benchmarking Activity:

The team decided that it might be useful to perform a benchmarking activity with regards to the conditioning of air bag inflators. Some members of the team held the opinion that the conditioning step is a heat treatment, and wanted to adopt controls similar to those used by Ford's Worldwide Heat Treat Standard, WHT-X. The team eventually decided that the most reliable "heat treatment" example was not in the industrial sector at all, but in the food service industry. McDonald's French fries were judged to be among the most consistent heat treated product known.

After arranging with the local McDonald's manager, the team (wearing McDonald's hats to cover our hair) toured the French fry cooking operation. Findings from this informative and somewhat high calorie trip included the following:

1. Timers are preset on the fryers, and measure the total time elapsed in the cooking oil.

2. This kitchen used an automatic withdrawal system that raised the fry baskets over the oil upon alarm acknowledgement.

3. Times were kept the same for French fries and hash brown potatoes in the morning.

4. The chicken baskets had different timer settings since the cooking time was different from that of potatoes.

5. There were visual signals for correct oil temperature, and workers were verbally instructed not to cook if the oil was too hot or too cold. However, there was no physical or programming barrier to keep them from inserting food into incorrect temperature oil.

On the basis of the bench marking activity, as well as the operations of some of the other Autoliv facilities located in Asia and Europe, the following corrective actions were decided upon:

- Some sort of timing device would be installed on each of the ovens, indicating the elapsed time that inflators had been in the oven. An alarm would signal when the inflators were available to be tested at the conditioned temperature.

- Standardization efforts would be commenced for the test temperatures and times in which we tested inflators. It was decided that the fewer permutations possible for testing, the less chance of inadvertent error by the operator.

A presentation of the findings thus far was presented to the automotive representative. He was much amused at the McDonalds benchmarking activity, but became quite interested at the technical details of the alarm and timing system they use. They have had similar issues regarding timing on epoxy applications in the assembly of the automobile, and indicated that there may be a trip to McDonalds made by some of their problem solving teams. He agreed to the recommendations made by the Autoliv team, and we were given permission to proceed with a trial implementation of our recommendations.

Implement and Validate Permanent Corrective Actions

Sub-teams were formed to work on the various components of the approved permanent corrective actions. Results of each of these implementation and validation activities are discussed separately below.

Implementation of Standardization on Timing:

The team determined that there were three standard times used in conditioning inflators, 60, 90, or 120 minutes, depending on previously performed temperature studies. SAE/USCAR-24, the governing procedure for qualification and testing of airbag inflators requires that inflators be conditioned for 125% of the time for temperature equilibrium based on internally mounted thermocouples.

Errors had occurred most frequently in calculating the 90 minute times. It was decided that an initial corrective action would be to increase the 90 minute time in the oven to 120 minutes, reducing the number of variables, and not overly affecting the productivity of the testing activity. This change was approved by our customer and has been implemented in the revised Operating Procedures.

Validation of Standardization on Timing:

An audit was conducted for the three conditioning areas in Northern Utah Autoliv North America facilities for the conditioning time of inflators. For a three week period, there were 418 inflators conditioned and tested, and no errors were detected. An interview with the test technicians indicated an appreciation with the simplification of the testing time. As one of the technicians said, “The new system is easier. Small inflators are conditioned for an hour, big ones for two.”

Implementation of Standardization on Temperature:

One of the sources of errors was found to be the six variations of temperatures for non-ambient inflator testing. Standardization of the temperature to a single test condition would remove the people factor from the equation, and result in lower costs for equipment.

Customer specifications for the conditioning temperatures of LAT’s indicate the testing temperature, typically with a range of plus or minus five degrees. The team’s contention is that this gives us an option to test 80°C inflators at 85°C and 90°C inflators at 85°C. Several of our customers disagree, claiming that the allowance is for temperature variability within the conditioning oven. For initial qualification testing, the USCAR-24 specification is clear, with the high temperature conditioning at 85°C. Resolution of this issue awaits a decision from the Vice President of Global Quality, located in Stockholm, Sweden.

In the interim, we have made the testing temperature for each inflator test sequence a larger font and bolder than the rest of the instructions so as to increase the readability of this parameter. We have also designate 85°C as the default high temperature test condition. Customers that require 80 or 90°C have this temperature added to the “Special Instructions” section.

Validation of Standardization of Temperature:

In the same internal audit of conditioning practices listed above, the temperature of conditioning was examined. Of the 418 inflators tested, there was one error noted where inflators requiring 80°C conditioning was performed at the more common 85°C temperature. The technician that made the error was actually a supervisor filling in for a sick co-worker. This supervisor was from another area, and had not attended the roll-out presentation of procedure and instruction changes. Since the testing was performed in the more severe condition, it was decided that the testing error would not be communicated to the customer.

Implementation of Testing Oven Timers

A feasibility study was conducted using the conditioning ovens in the prototype testing facility because of the smaller volume of tests conducted there in comparison to the manufacturing plant. The study involved what type of timer would be used, and how many timers were needed for the conditioning area.

One of the technicians from the area obtained a kitchen timer from her house. After using it for two shifts, she reported mixed results. Among the concerns she and others had were the following:

- She tended to forget to set the timer since it was new to the area.
- She couldn’t remember which oven the timer was applicable to, and had to refer to her instruction sheets where she had recorded the loading times

- Once the alarm was turned off, a distraction would occur and she would forget about the alarm. Having inflators reside longer than required is not considered a quality issue, but it limits the number of inflators that can be tested in a shift.

- A quality auditor noted that a home type timer was not applicable for an industrial application, since it was not calibrated. We asked whether we could perform verification on the timer with a calibrated timepiece, and was told no. No reason was offered for the negative stance.

A review of industrial timers available for our application was conducted by team members from Engineering and Maintenance. The requirements for these timers were set by the team.

- The timers had to be industrial style so that we could put a calibration sticker in conjunction with the Quality Department and Metrology.

- The timers needed to be fairly low cost. One of the needs identified through the timer trial was that one oven could have as many as three tests running concurrently. The shelves of the conditioning oven may have three inflators loaded at 9:20, one test loaded at 9:45, and six inflators loaded at 10:00. It was determined that the 85°C ovens needed to have three timers, corresponding to the holding racks inside.

- The timers had to be small enough to be placed on the oven itself.

- There had to be an alarm function.

- There needed to be an easily visible time for the operator to know how much longer there was in the cycle.

- The timers had to be programmable for the 60 or 120 minute preset time. This programming had to be tamper proof from the operator, but accessible for the maintenance technicians.

- The timers should be battery operated so that no wiring for power cords would be required.

Based on the above requirements, the Veeder Root timer was selected for the initial installation in the prototype testing facility. A photograph of one of the models under consideration is listed in Figure 2.

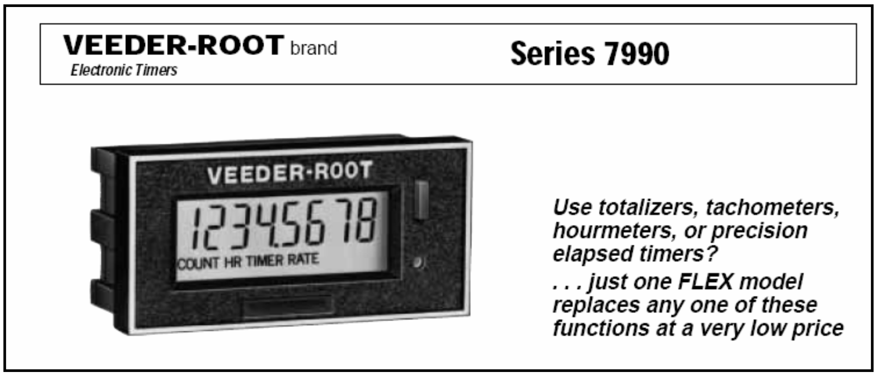

Figure 2: Veeder-Root Timer

A total of eight timers were purchased for the initial trial. The Maintenance Department spent an entire day, making several phone calls to the Veeder-Root people to learn how to do the required programming. It was determined how to count down from a preset 60 or 120 minutes, and then alarm.

The one issue the group could not resolve was resetting. There are times when the operator may have to scrub the test due to an equipment malfunction or some other situation. In this case, the technician can cancel the countdown so an alarm won't go off or the timer can be reset when he or she is ready to reload and restart the conditioning. This ability to reset also means that an operator can push the restart button and mess up the countdown. The timer can be set only one way, but not allow for both.

The team decided that the timer is an observational and assistance tool, not truly controlling the conditioning oven. The actual objective evidence for procedural conformance would continue to be the instruction document where load times and unload times were recorded.

Validation of Testing Oven Timers:

It has only been several weeks since the eight timers were installed on the conditioning ovens. All have been reliable, with only a few feedback items from the technicians:

- The alarm sound is somewhat annoying. The team agreed, but there is no feasible way to reprogram the sound. Alarms by their nature are designed to get attention.

- It is hard in the testing bay to determine which alarm is sounding. The team indicated that there is a visual indication from the timer face. At present, the technician will have to track the alarm by sound and peering at each of the ovens to find the source.

- Programming the timers was difficult. However, now that we know how to do it from the first eight units, additional ones should not be as bad. We have requested the programming instructions to be recorded as a Work Place Instruction for other Maintenance employees.

- The alarm signaling and acknowledge cycle is not ideal. The perfect system would have a large flashing light to indicate the timer had counted down. Upon alarm acknowledgement, the light would stay lit until the inflators were removed from the oven and deployed. At that point, the alarm-acknowledge could be depressed again to indicate that testing was complete. We could not find a simple timer that could perform this function. Future ovens might be built utilizing this type of built-in timer and alarm system.

An audit of the timing of inflators was conducted. It was found that the average time from oven loading to deployment of one hour conditioning time inflators dropped from 84 minutes to 70. The alarm serves as a powerful and annoying reminder that the inflators are ready to be tested. There is thus an unexpected benefit to an alarm in increasing the productivity of the testing areas. Similar reductions in testing time were also observed in the two hour conditioning time inflators.

For the inflators tested at the prototype facility, no discrepancies or errors in the testing time were noted. Whether this improvement is from the timers or the amount of time and attention given to the testing area cannot be discerned. This could be an example of the well known Hawthorne Effect, where productivity improvements were noted at a telephone factory by adjusting the lighting levels. It turned out that it was the attention given to the workers by management, rather than the lighting levels that was the factor attributed to the productivity improvement.

Prevent Recurrence:

At Autoliv North America, this 8D step for the prevention of recurrence is interpreted two ways. The first interpretation is for the incorporation of the corrective actions into permanent procedures, standards, instructions, or machine specifications. The second interpretation is known by the Japanese term yoko-ten, and refers to the concept of incorporation of the new methodology throughout the organization.

Procedural and Standard Changes:

The procedures in the testing bay at the prototype bays have been changed to require the use of the timers and alarms to signal when the elapsed time allows for inflator testing. The standards for conditioning inflators throughout North America have been changed to 60 or 120 minutes, depending on the size of the inflator. The purchasing standard for new conditioning ovens will require a timer and alarm cycle similar to that described above.

Yoko-Ten Activities:

With the apparent success of the timer installation in the prototype testing facility, the other two testing centers in Northern Utah are in the process of ordering timers for their conditioning ovens. The type of timer is similar but not identical to that in the prototype testing facility. One of the maintenance people at the manufacturing facility has experience with another timer brand, and chose to make the purchase of that type. The brand of timer was judged to not be as important as the common function it will serve.

Autoliv Corporation has inflator facilities in Utah, France, Romania, Japan, Sweden, and one in China under construction. In order to communicate the corrective actions in one facility to the rest, a Global Lessons Learned database has been developed. This database was designed to capture corrective actions, best practices, problem solving activities, and failure analyses. As part of design validation, production validation, and start of production, a search of this database must be completed, and adoption of applicable practices is required. The identified corrective actions relating to conditioning times and temperatures have been added to the Lessons Learned Database. In addition, the corrective action implementation items have been E-mailed directly to the managers of the testing facilities worldwide.

Recognize Team and Individual Contributions:

The customer as well as Autoliv management have been pleased with the progress of problem resolution and the quick adoption of permanent corrective actions in addressing this audit finding. Members of the team received a written commendation for their employee file, and were given $50 gift certificates to Olive Gardens. They joked it should have been McDonalds.

Conclusion:

Audit findings are one of a number of problems encountered in a technical production situation that can best be solved utilizing a formal methodology. Deming indicated in his discussion of the PDSA cycle that continuous improvement is key to maintaining competitiveness in any market situation. The Ford Global 8D approach is only one of many successful problem-solving methodologies. This Human Factors Engineering class has taught that many problem situations relate back to the people involved. Failure to consider the human factors will result in a sub-optimized solution.

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