THE ROLE OF PROCESS FMEA IN ASSESSING RISKS AND IDENTIFYING SAFETY DEVICES FOR MECHANICAL PRESSES: THE CASE OF AN AUTOMOTIVE SUPPLIER

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Abstract. *This paper presents an application of the well known technique of Failure Mode and Effect Analysis, or simply FMEA, in assessing risks and identifying safety solutions for mechanical presses used in the manufacturing processes of automotive parts. The concern with press operation safety has become particularly intense after the Collective Convention for the Improvement of Working Conditions in Presses and Similar Equipment was signed a couple of years ago by the Federation of Industries of the Sate of São Paulo (FIESP) and several institutions representing both employers and employees under the auspices of the Ministry of Work and Employment (MTE). As shown throughout this paper, process FMEA has revealed itself as a very effective tool not only for improving the process proper, but also for gaining a deeper understanding of the risks involved, as well as for identifying those safety measures that should be taken in order to deal adequately with such risks.*

Keywords*: FMEA, mechanical presses, process, risk assessment, safety.*

1. INTRODUCTION

It is well known that present day competition drives companies to constantly struggle for better production processes and greater productivity in order to secure good financial results and attain their planned objectives. In many companies of the metalwork industry, however, this constant quest for survival has produced a higher risk level for operators when using automation devices associated with mechanical presses in the realization of materials transformation and cutting.

Accordingly, the Federation of Industries of the Sate of São Paulo (FIESP) and several institutions representing both employers and employees of the Metalwork, Plastic, Electroplating and Automotive industries, under the auspices of the Ministry of Work and Employment (MTE), have signed on November 29th, 2002, the Collective Convention for the Improvement of Working Conditions in Presses and Similar Equipment, that was revised on April 20th, 2006, aiming at assuring adequate protection to the physical integrity and health of workers involved.

In order to comply with the terms of said Convention, companies employing presses and similar equipment may choose between installing devices such as light and presence sensors acquired from external suppliers, or to try and use alternative internal solutions. The latter may be considerably cheaper and as effective.

A large automotive supplier, producer of a wide variety of pressed, machined and painted products, chose to use PFMEA (Process Failure Mode and Effects Analysis) associated with three other quality tools, namely: Process flow-charting, 5 Why's (Slack et al., 2002) and Poka-Yoke (Shingo, 1996), in order to develop an internal solution for safe press operation in compliance with the aforementioned Convention.

2. MECHANICAL CAM PRESSES

Mechanical cam presses are machines where a rotating motion is converted into linear motion by means of cranks, connecting rods, bearings and shafts in order to produce the desired pressing effect. Figure 1 shows an example of a cam press where an electric motor maintains the flywheel in constant rotating motion. A key is used to engage the flywheel and the transmission shaft and thus start the hammer in its linear downward motion.

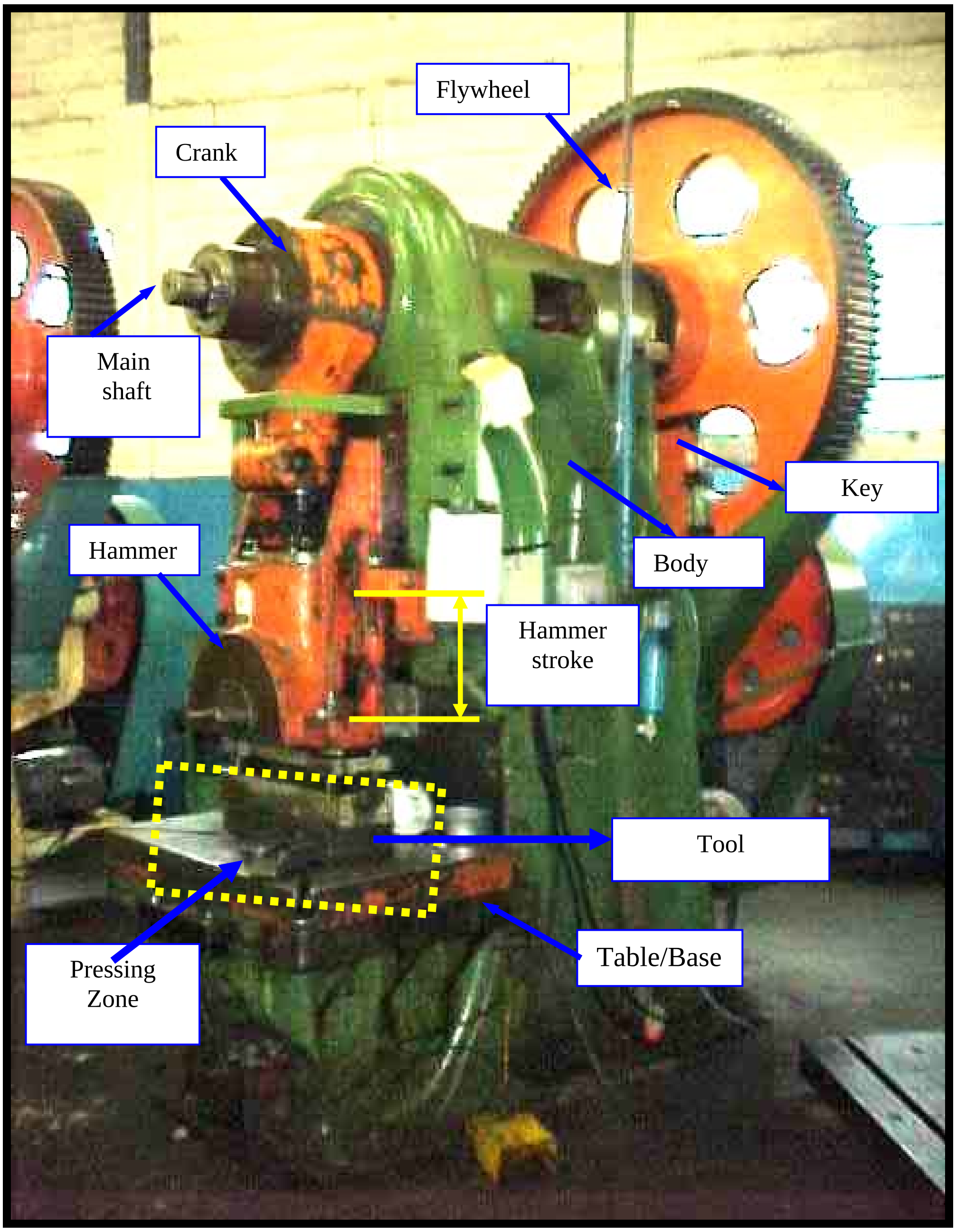

Figure 1. Key driven cam press.

The safety problem studied and described in this paper refers to the *pressing zone* shown in Fig. 1 where the linear pressing effort is applied in order to perform the desired forming operation.

3. PFMEA (PROCESS FAILURE MODE AND EFFECTS ANALYSIS)

3.1. PFMEA as a quality tool

The PFMEA (ANFAVEA, 1998; 2001) is a preventive analytical tool by means of which an engineering team can identify potential failure modes in processes while these are still in the design stages. Therefore, through careful technical discussions aimed at assessing the risks involved, it is possible to try and eliminate the undesired effects of such failure modes by means of preventive actions that hopefully will eliminate or at least considerably reduce said risks.

As manufacturers look for increasingly capable production processes, the PFMEA becomes more and more popular among companies in the automotive industry, since this technique has revealed itself as an efficient means of eliminating possible failures in manufacturing processes and therefore a very useful tool for reducing losses, waste and undesirable costs, enhancing product quality and increasing the competitive edge.

3.2. PFMEA as a safety tool

Bearing in mind that the PFMEA is essentially a preventive tool capable of identifying failure modes and its consequences as well as assessing the potential risks involved, it is not difficult to imagine that it might also be advantageously used for preventing accidents and their consequences. In other words, that it could be used in the design and development of safety systems intended to assure the physical integrity and/or good health conditions of workers.

A similar reasoning led the authors to consider the use of this technique in order to assure the effectiveness of a protection grid for the *pressing zone* of the cam press under consideration. It was perceived that the use of the PFMEA technique would make it possible to carry out the identification and classification of risks, as well as to take whatever precautionary measures might be necessary to eliminate or reduce the possibility of occurrence of failures capable of generating accidents.

Timing is a crucially important factor for the success and effectiveness of FMEA application in the prevention of failures in safety systems. The FMEA analysis must be completed before the incorporation of a failure mode into the safety system or into the process of realization thereof. In other words, a careful analysis of failure modes and their effects must be carried out in the early stages of design both for the safety system proper (Design FMEA) and for its production process (PFMEA) before the production and instalation stages.

4. APPLICATION OF PFMEA IN THE ANALYSYS OF A SAFETY SYSTEM FOR A CAM PRESS

The safety system was designed to enclose the *pressing zone* by placing a protection grid and sensors capable of detecting both the opening and the dismantling of the system. This safety system was conceived to render it impossible to operate the press if the protection grid is out of position or with the door open.

When the authors undertook the work that is being described the grid system had already been designed. This is the reason that just a PFMEA analysis was carried out and not a DFMEA. The PFMEA, however, was meant to be as comprehensive as possible and was conducted in two phases: grid production process analysis and grid assembly and test process analysis. It was hoped that in so doing it would be possible to detect failures not only in the processes but even in the grid design.

In the production process all manufacturing and component assembly steps were flow-charted and investigated . The same was done regarding the process of assembling grid components onto the press and testing them for good operation.

4.1. Production process analysis

The study was carried out by the PFMEA team using the standard form contained in the QS 9000 Reference Manual (ANFAVEA, 1998), where all steps of the grid manufacturing process where considered as identified through the flow-charting tool. The potential failure modes and the corresponding effects were described together with their respective severity classes. Then:

- Potential root causes for the detected failure modes were determined using the “5 Why’s” quality technique;
- The probability of occurrence of each failure mode was ranked;
- Existing prevention and detection controls were listed;
- The effectiveness of the existing detection system was ranked;
- The Risk Priority Nº (RPN) was calculated.

Whenever the RPN >100 (Critical Point) preventive or improvement actions were taken, after which the RPN was re-calculated, thus assuring the effectiveness of said measures and also that no failure mode had a RPN>100 in the grid manufacturing process.

As a result of PFMEA application to the grid (sides and door) manufacturing process, 18 Critical Points were detected among the 25 flow-charted process operations (OP). Accordingly, 15 preventive actions were recommended by the team and taken. The difference between 18 and 15 is explained by the fact that some preventive measures were applied to more than one Critical Point. Some of the main actions taken during this study and the corresponding process operations numbers were:

- OP-04 – Stock identification and product protection in order to avoid oxidation and life reduction.
- OP-10 – Roughing-off added to the cutting operation in order to avoid the presence of burrs in subsequent operations.
- OP-10 – Revision of the Inspection Plan to include roughness control.
- OP-10 – Realization of device for supporting and positioning grid components for the cutting operation in order to avoid loss of material and assembly failures that might allow access to the *pressing zone* as shown in Fig. 2.

Figure 2. OP-10 – Device for cutting operation.

- OP-20 - Realization of device for correctly positioning grid components for the welding operation in order to avoid loss of material and assembly failures that might allow access to the *pressing zone* as shown in Fig. 3.

Figure 3. OP-20 – Device for welding operation.

- OP-20 – Drawing up of a MIG Welding Instruction in order to specify welding parameters and standardize welding operations.
- OP-20 – Revision of the Inspection Plan in order to include set-up and destructive tests and assure a better inspection of welding operations.
- OP-50 - Drawing up of a Painting Instruction in order to specify temperature and drying duration parameters and standardize paint drying operations.
- OP-50 – Purchase of a time control device with alarm in order to warn the operator and assure standardization of drying durations.

4.2. Grid assembly and test process analysis

This analysis phase was carried out in much the same way as the previous PFMEA for the grid production process. After all analyses had been concluded the effectiveness of the existing detection system was rated and the RPN was calculated. Here also for all instances where RPN >100 (Critical Points) preventive or improvement actions were proposed, and once taken new analyses were carried out and new RPN values calculated thus assuring the effectiveness of proposed measures and also that no failure mode had a RPN>100 in the grid assembly and test process.

As a result of PFMEA application to the grid (sides, door and sensors) assembly and test process, 29 Critical Points were detected among the 14 flow-charted process operations (OP). Accordingly, 19 preventive actions were recommended by the team and taken, some of them applied to improve more than one Critical Point. Some of the main actions taken during this study and the corresponding process operations numbers were:

- OP-01 – Revision of the grid components manufacturing process in order to add a roughing-off activity at the end of every phase.
- OP-10 - Drawing up of an Assembly Instruction in order to specify maximum clearances and prevent access to the *pressing zone*.
- OP-20 – Revision of the grid manufacturing process Control Plan in order to assure grid height checking and prevent access to the *pressing zone*.
- OP- 20 - Addition, as requested to the Engineering Department, of lock nuts for the screws that attach the grid onto the press.
- OP-20 – Addition, as requested to the Engineering Department, of horizontal grilles in order to provide more than one access for raw material introduction, and at the same time so spaced as to prevent the introduction of the operator's hand as shown in Fig.4.

Figure 4. OP-20 – Raw material access grilles.

- OP- 21 - Drawing up of a Working Instruction in order to specify which items should be inspected during tests carried out to assess the safety system and the possibility of access to the *pressing zone*.
- OP- 30 - Addition, as requested to the Engineering Department, of a 400 mm ramp in order to provide an easy exit for pressed parts, and at the same time to prevent the introduction of the operator's hand.
- OP- 40 - Alteration, as requested to the Engineering Department, of the door locking device in order to place it on the inside of the grid as shown in Fig. 5(a).
- OP- 40 - Alteration, as requested to the Engineering Department, of the door rail device, closing the passage to the moving part as shown in Fig. 5(b).

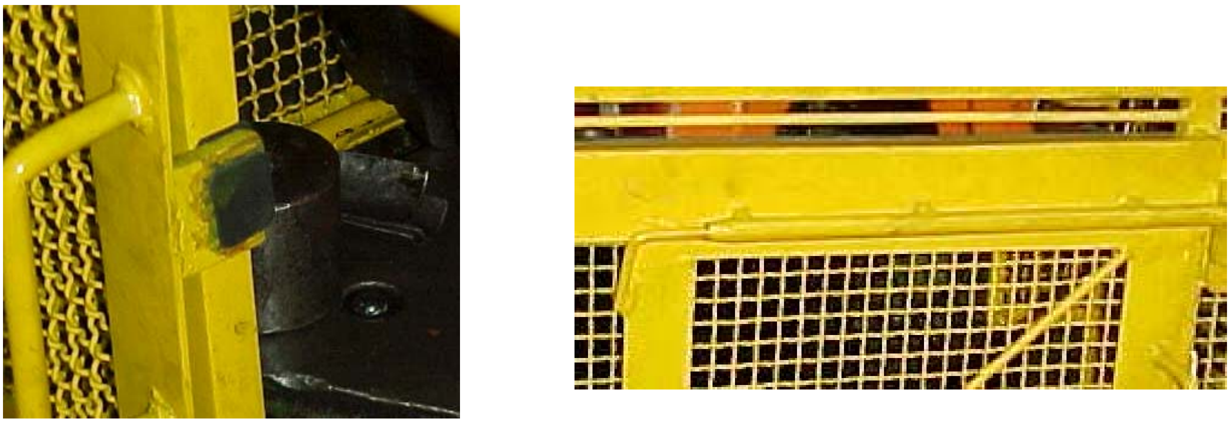

Figure 5. OP-40 – (a) Door lock; (b) Door rail closed.

- OP- 41- Drawing up of a Working Instruction in order to specify which items should be inspected during tests carried out to assess the door safety system.

- ➢ OP- 50 - Alteration, as requested to the Engineering Department, of the sensor actuating system and the shielding thereof in order to prevent operation with the door open as shown in Fig. 6.
- ➢ OP- 50 - Alteration, as requested to the Engineering Department, of the sensor actuating system with the installation of one sensor for the shutting of the door and another sensor for the operation of the press.
- ➢ OP- 50 - Alteration, as requested to the Engineering Department, of the safety system for sensor actuation with the installation on the door of a second end-of-travel sensor in order to ensure the closing of the door in case of failure of the first system.

Figure 6. OP-50 – Shielded sensor.

As a result of the adoption of recommended actions the grid assembly and installation process could be considerably improved, and all Critical Points, that is those points where RPN > 100, were eliminated and brought to a level that is acceptable to the PFMEA team, i.e. NPR < 100. Furthermore, improvement opportunities were also detected during the PFMEA analysis in the grid design, which generated design alterations and the reduction of the probability of accident occurrence during press operation.

5. CONCLUDING REMARKS

This study was conducted according to the basic idea that PFMEA, being essentially a preventive tool, could not only be applied to production processes, but could also be advantageously used in connection with other processes, particularly with those processes intended to assure the physical integrity and/or good health conditions of workers. Besides it was also envisaged that the effectiveness of PFMEA could be significantly enhanced when used in conjunction with the “5 Why’s” and “Poka-Yoke” quality techniques.

By applying PFMEA to the grid production process, it was possible to detect 18 Critical Points in this process, and accordingly take 15 preventive actions recommended by the PFMEA team. A comparison of process conditions before and after such actions were taken is shown in terms of NPR in Tab. 1.

Table 1. Grid production process: NPR comparison.

PFMEA	**NPR** Total	**NPR** Average/Critical Item
Before	3346	167,3
After	1404	70,2

It can be seen in Tab. 1 that as a result of PFMEA and its associated actions the risk level in the grid production process was significantly reduced, producing a safer and more reliable process.

On the other hand, by applying PFMEA associated with the “5 Why’s” and “Poka-Yoke” quality techniques to the grid assembly and test process, it was possible to detect 29 Critical Points, and accordingly take 19 preventive actions recommended by the PFMEA team, six of which actually were requests to the Engineering Department for alterations in the grid design, A comparison of process conditions before and after such actions were taken is shown in terms of NPR in Tab. 2.

Table 2. Grid assembling process: NPR comparison.

PFMEA	**NPR** Total	**NPR** Average/Critical Item
Before	4872	152,25
After	2114	60,06

It can be seen in Tab. 2 that as a result of PFMEA and its associated actions the risk level in the grid assembly and test process was considerably reduced, producing a safer and more reliable process, as well as improving the grid design.

The authors are quite convinced not only of the validity of the PFMEA use in connection with processes intended to assure the physical integrity and/or good health conditions of workers, but also that the final safety system herein described would not have achieved its final configuration, entirely to the satisfaction of all parties involved, without the help of PFMEA.

6. ACKNOWLEDGEMENTS

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