



SCREW TORQUE TRACEABILITY CONTROL: INDUSTRIAL APPLICATION

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ABSTRACT

This paper analyses a new screw torque traceability control procedure designed for an operation in a car audio workstation. First the detection score at a Failure Mode and Effects Analysis (FMEA) indicated which process improvement were needed. On the sequence, data was collected to evaluate performance indicators. Finally, specific actions were executed based on the improvement plan. As result, the FMEA detection score improved from 7 to 3, the run rate increased from 12 to 16 products/h and defects caused by improper screwing were eliminated. This research contributes to disseminate a practical application of a screw torque traceability control.

Keywords: screwdriver; torque; screw; traceability; FMEA.



1. INTRODUCTION

Screw-tightening is an important assignment in assembly processes due to their wide use in various types of manufactured products. For example, about three million screws are used in a plane, and about three thousand screws are used in an ordinary car (Li et al., 2009). According to Ogushi et al. (2015) in almost all precise electrical and mechanical parts, hand torque screwdrivers are used for the fastening control of screws.

In any kind of production process, not only the task should be properly designed but also the measurement system should be properly implemented to keep a good product quality and an efficient flow. For Chen (2014) and Berger et al. (2016), accurate measurement of external forces is also important in manipulation tasks involving tool-usage, the fastening torque and the angular displacement of the screw have to be closely monitored.

Muelaner et al. (2010) describe "the accuracy of the measurement system is lower than that of assembly design takes place", calling this statement as a phenomenon. Currently, industries are still using hand torque, screwdrivers are used for the fastening control of screws and torque traceability is almost non-existent.

Motivated by the challenges of torque control in car audio production process and based on the literature, this paper applies an action-research methodology for analyzing and improving the automation of screwing and measuring torque performance processes. Also, torque traceability control was achieved with the improvements applied, contributing to disseminate a practical application of a screw torque traceability control, which allows the verification and the validation of a basic requirement in several productive processes and industries.

2. THEORETICAL FRAME

To assure the strength connection throughout the life length of a car, critical issues must be developed not only to the design of the joint but also to the assembly operation (Hermansson, 2016). Screw connection is one of the most prevalent connection method in the assembly industry, in which impact wrench plays an important role (OGAWA et al., 2015; GANESHMURTHY; NASSAR, 2014; WOLF; LORENZ, 2011).

Associated with screw connections, the pushing force and the rotary torque are required for screw tightening, which can be performed by humans or automated machines. Humans tighten the screws based on their feelings or on their experiences by feeling the reaction torque and force through the screwdriver. Electrical screwdriver is a precise method to control the

rotary torque, "it can rotate a screw in high angular velocity, and come to a stop at the end of screw tightening in order to prevent applying excess rotary torque to the product" (OGAWA et al., 2015).

Liu et al. (2015) emphasize that in a screw-tightening performed by humans, the pre-tightening torque and effectiveness of the assembly process are determined to the operator's experience and improper pre-tightening torque can cause screw defects, thus automatic screw tightening machines are essential in modern assembly industry. Wen et al. (2016) add the great significance of the measurement and control of the interaction force between components to maintain the quality of the final product. Bischoff et al. (2010) wrote about the emergence of robots with joint torque sensing and feedback control.

Persson and Roloff (2016) define the tightening methods implemented in production for reaching a specified clamp force, which are:

1. Torque control: when tightening shuts off at a predefined torque level T , it is called torque control. Often it is carried out in two steps, a high-speed rundown until mating of all parts which occurs at a low torque, and a lower speed when aiming for the target torque. Tightening using torque control can only be made in the elastic range of the fastener;
2. Angle control: is when the target value in the last step is an angle, ϕ . This method is often carried out with a torque step as first step to make sure that all parts have mated. Angle control can be used both in the fasteners elastic and plastic range;
3. Gradient control: when tightening into the plastic range, gradient control can be used. In this method, the gradient of the torque angle rate is evaluated. Target is reached when a predefined gradient $\Delta T/\Delta \phi$ is reached;
4. Clamp force or elongation control: is based on bolt elongation measurement. Mechanical and ultrasonic elongation are examples of methods to measure the clamp force/elongation. Clamp force control has been investigated thoroughly; however, implementing it in production has been slow, due to the difficulty of assuring correct measurements and repeatability. Thus, manual measuring, before and after tightening, is costly and labor intensive.

3. METHODS



The need of this research was triggered by the FMEA evaluation during a New Product Introduction (NPI) project. According to Schneider (1996), FMEA is used to evaluate a new system, or design, or process or service taking into consideration all possibilities of failure occurrence. It is focused in discovering and controlling problems before their occurrences. First, all the potential failures are identified; on the sequence, a critical analysis is performed taking into account three risk factors: occurrence (O), severity (S) and detection (D); finally, the Risk Priority Number (RPN) is determinate by the multiplication of the O, S and D values of a failure (LIU et al., 2013). The highest priority must be given to the failure modes with highest value of RPN whose are supposed to be more critical those having a lower RPN (SAFARI et al., 2016). Corrective actions must be executed and the RPN should be recalculated, to check the efficiency of these actions (LIU et al., 2013).

The methodology applied in this study is empirical based on action-research concepts. Tripp (2005) states that action-research is one of the many different ways of investigation and action; he defines it as any continued, systematic and empirically justified attempt to improve the practice. He also groups the four phases of the basic cycle of action-research into two big phases: (1) action composed by planning and acting stages and (2) research composed by monitoring and evaluating stages.

The empirical methodology applied in this study follows the following steps:

1. Problem definition based on high RPN found during the FMEA study;
2. Cause analysis performed by process specialists;
3. Improvement actions taken by process specialists;
4. Results, based on the RPN recalculation and improvement of other indicators.

4. INDUSTRIAL APLICATION

4.1. Object of study

The presented study was applied in a multinational industry that designs and manufactures audio products for automotive companies, they market for more than twenty brands around the world. Company has part of production dedicated to contract manufacturing services and follows a lean manufacturing culture. The issue analyzed occurred in the workstation “Display Assy 2”, where chassis, front panel and top cover are screwed.

4.2. Problem definition

During the plan phase of the NPI project, to assure an effective production process in product failures prevention, a multidisciplinary team evaluated the FMEA. The team reported that all defects related to the screw fixing process (badly assembled, missing, dusted, broken and wrong) had high severity in potential failure mode (8 score points), low cause occurrence (2 score points) and high detection control (7 score points), accounted 112 score points of RPN. Based on this score, the conclusion was that the main problem was related to detection and it should be necessary take improvement actions to reduce the detection control score.

4.3. Cause analysis

The high score in detection control stemming from the manual torque process, which the detection probability is too low. The electrical screwdriver did not have transducer and the process control used to evaluate the torque was manual, depending on the operator's skills. Figure 1 shows the resources (Manual jig and electric screwdriver) used to perform the operation in the workstation Display Assy 2. Although the electrical screwdriver met the whole product requirements, it did not have the ability to program different torque specifications at the same time. Therefore, the adjustment was performed manually, using an external torque wrench to set the exact value to be applied. In addition, it was not possible to have individual screw torque traceability using this manual screwing process.

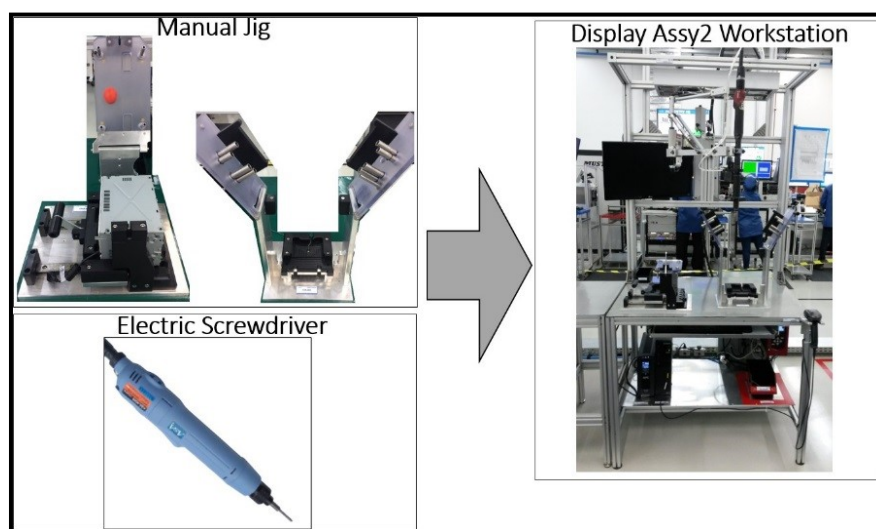


Figure 1: Manual jig and electric screwdriver used in Display Assy 2 workstation

4.4. Improvement actions

The acquisition of a new electric screwdriver with controller, and the design of a new semi-automatic jig (figure 2) changed the performance of the Display Assy 2 workstation, improving the detection and ensuring the torque traceability control for each product, ensuring reliability to the customers.

Automation and mandatory assembly sequence was taken into account during the jigs development, considering the use of sensors to detect parts of the products and avoiding operator's mistakes. The electric transducer screwdriver used to control traceability, enabled accuracy and assured error proofing. The tightening strategy for seating detection was implemented, and information about angle and torque parameters were considered in Manufacturing Execution System (MES) records.

The control of each screwing operation was feasible even with material variation due to the improvement actions applied. In addition, the screwing process was divided into two parts: (1) thread forming and (2) tightening.

For the thread forming phase, two options were possible:

1. Run down speed: the filament opening is defined according to a target torque value. This new target is obtained based on the observation of torque and angle-tightening curve in function of time. Values are analyzed after torque undulations due to opening of filaments;
2. Angle Run Down: it uses only the number of rotations to be performed, however, it is necessary to set the maximum torque and the safe value to avoid the "blanking" of the material. According to the team analysis, the "Angle Run Down" should be the best strategy, due to the option to avoid torque peaks in the beginning of the screwing process.

For the tightening phase (end of speed process), other strategies could be used: torque, torque and angle, yield point, seating detection and post seating detection. Nevertheless, "torque and angle" was chosen, due to its use with gradient of tightening is not feasible, allowing the best process control. In addition, the quality standard required by the customer could be kept.

In this automated process, the performance of the electric transducer screwdriver with controller was measured; figure 3 shows the aspects evaluated:

- Torque (blue line): in the beginning, a strong force is applied because the screw is opening the hole; after that the force is decreased, performing screw tightening; at the end, based on speed and angle information, the controller increases the force to achieve the torque specification;

- Speed (purple line): in the beginning, more rotations are used because the screw is opening the hole. Afterwards, the rotation is decreased to support the torque-applying step;
- Angle (red line): due the fixed value of the screw diameter, the angle shows a linear performance, the applied force does not influence this parameter.

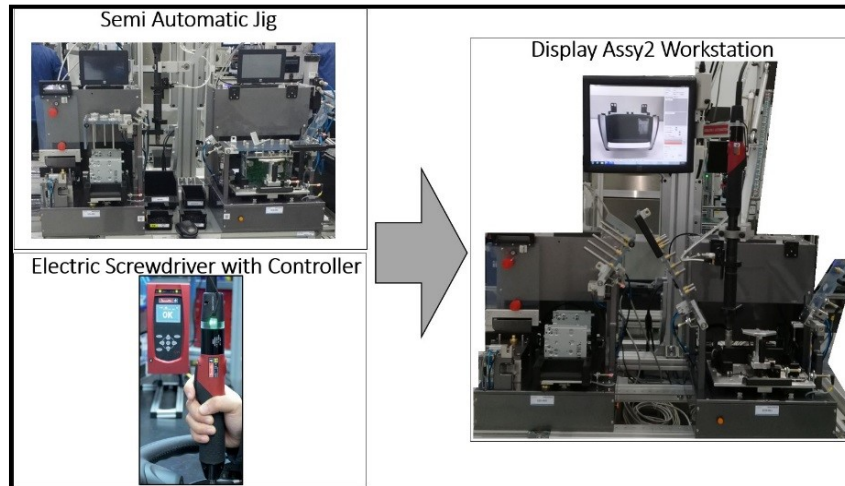


Figure 2: Semi-automatic jig and electric screwdriver with controller used in Display Assy 2 workstation.

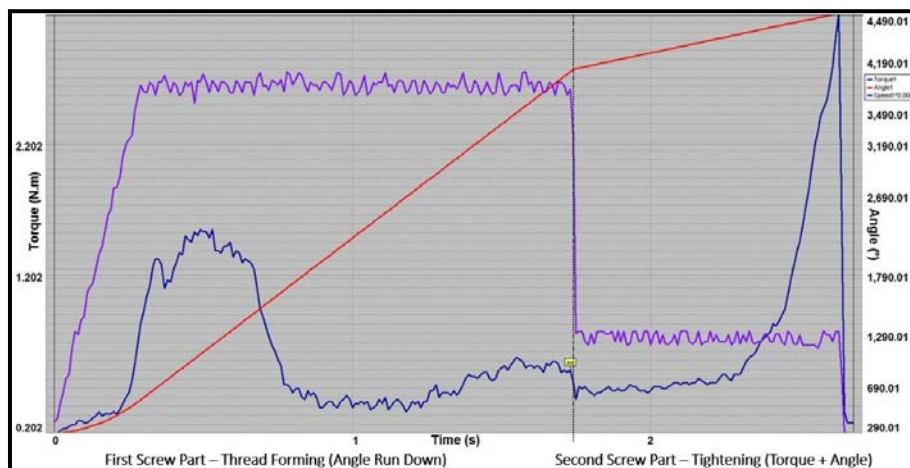


Figure 3: Torque curve performance during strategy definition – Torque (ft) x Angle (ft) x Speed (ft).

4.5. Results

The main achievements were evidenced as follow:

1. FMEA detection score (screw failures) was improved from 7 to 3 (this new score means that problems can be detected in the source, i.e. detection of failure mode in the station by automatic controls, preventing improper operation). This new detection score

improved the RPN (severity x occurrence x detection), from 112 score (8 x 2 x 7) to 48 score (8 x 2 x 3);

2. Traceability (that was lacking in the past) was feasible. Torque performance data for each screw according to the product serial number are stored in MES records;
3. Run rate increased from 12 products/h to 16 products/h;
4. Defects caused by improper screwing were eliminated: the screwing processing was automated, improving defect detection and quality control at the shop floor and, consequently, preventing failures, as shown in figure 4:

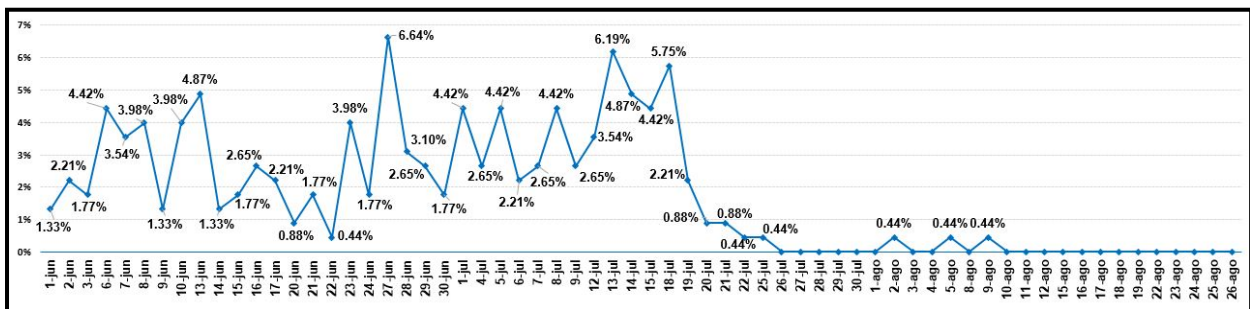


Figure 4: Daily defect control due to improper screwing.

5. CONCLUSIONS

This research analyzed a new screw torque traceability control procedure designed for an operation in a car audio workstation. Positive impacts from FMEA execution were evidenced with practical implementation of automated screwing process, as follow: (1) the FMEA Risk Priority Number was improved, (2) traceability control was established, (3) the production output rate was increased and (4) screwing defects were eliminated. Based on that, it is possible to state that the torque-angle strategy resulted in the best connection between the screwed parts, compared with the others. The research was applied in a real industry, consequently, besides the technical achievements, the involved team was recognized by the plant staff and the customers.

For future studies, it is important to keep focus on practical applications for other screwing strategies, analyzing screw types and the characteristics of the materials that will be connected. Variables of the product and the process should also be included in order to reduce defects and manufacturing costs.

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