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DESIGN FOR SIX SIGMA (DFSS) APPLICATION FOCUSING AUTOMOTIVE CONNECTION SYSTEM DESIGN IMPROVEMENT

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Abstract. *In the current global market scenario competitiveness is associated with the fact that consumers are increasingly demanding, seeking for high technical efficiency and total quality in their products, characteristics that have become real trend. Is known that where there are two or more members of the same segment, there is competition and consequently results in huge dispute for market survival. In many global industry sectors, including automotive industry for its great dynamism and speed, the development process demands great efforts and resources that have to be used correctly to ensure the assertiveness of the final product in regard to its performance as well as to the launch deadlines. An automotive connection system is a fundamental part of the complex structure of an automobile and represents a great potential for incremental and transformational improvements. The need for better products performance reflects the market more sensitive about the security and reliability requirements, making necessary the application of tools and methods for development. In this context, this article aims to present the DFSS method and its application with design of experiments getting an improved automotive connection system locking design respecting and meeting customer specifications and converging on a final improved and robust performance.*

Keywords: *DFSS, Product Development, Performance*

1. INTRODUCTION

Bosch (2004) defines an automotive connection system as the component responsible for the union of two independent circuits in the car wiring harness and usually consists of three main parts which are plastic part, responsible for the mechanical requirements, metal part, responsible for electrical requirements and silicon part, responsible for sealing against water, moisture and salt spray. Nicolas (2010) completes the automotive connection system definition as a fundamental part in the complex automobile structure having great importance on reliability, safety, innovation and automotive technology, and represents a great potential for improvement. The performance improvement quest is fostered by research and development in engineering design and materials.

Aiming at a better understanding of scope and object study of this technical work and research, is presented in Fig. 1 an example of automotive connection system.

Figure 1. Automotive connection system

Novaes (2011) describes: "It is sensitive the real and upcoming trend in the industrial sector with investments in research and development of alternatives in order to meet more stringent technical requirements being supported by

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sectors including government, giving birth to the era of constant development." According to Fernandes, et al., 2010, is expected that in the near future, automakers increase the demand for components improved in performance and efficiency point of view.

A major concern in this topic is the trade-off between the shrunken development time and undeniable need of assertiveness on the robustness and performance of the final product. Reduce product development time is mandatory and becomes an essential requirement in new developments in regard to competitiveness as well as maintain and sometimes exceed product performance and quality levels. Thus, methods and tools should be applied in the development process from initial design and concept, aiming at high-performance products. To meet this need was created in the late 90's the proactive technical method for robust product development aiming six sigma products, DFSS (Design for Six Sigma). Structured and originated from Six Sigma, DFSS method brings a different approach and a set of tools dedicated to product development, making it unique and special in its application, as defined by El-Haik and Yang (2003).

In this context, this technical work will present the application of DFSS method under the technical point of view in the product development process of an automotive connection system lock feature optimized in its requirement for mechanical looking performance. For a complete and better understanding of the method application in product development, was selected a connection system lock design, example shown in Fig. 2, which has as function locking connector with the mating-part, being it another connector or a vehicle subsystem. The output variable analyzed was tensile pull strength (pull force) in the assembly, measured in newton (N) and the main input factors considered were three basic dimensions of the lock, measured in meters (m).

Figure 2. Connection system lock

2. THEORETICAL BACKGROUND

2.1 Connection System

An Electrical Automotive Connection System is the component responsible for the union of two independent circuits in a car wiring harness. There are basically three fundamental parts in automotive connection system, as described by Bosch (2004) and shown in Fig. 3: Plastic part, well known as connector; metal part, well known as terminal and silicon or rubber part, well known as seal.

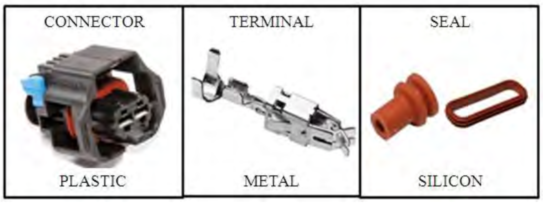

Figure 3. Automotive connection system elements

For Delphi (2011), the plastic part of an automotive connection system has the basic function of electrical insulation and mechanical requirements. Usually manufactured by injection process, is made of polymers in their different kinds and compositions. Must have high mechanical strength and electrical and thermal conductivity tending to zero in order to thermally and electrically insulate conductive parts. As secondary functions it also has to mechanically protect the entire system, be the housing for the other parts of the connection system, the assembly and retention of the mating part, among others.

The metal part of an automotive connection system has the basic function of electrical current and power conduction. It is manufactured by stamping process and is generally made of metallic alloys. Must have high electrical conductivity, the main characteristic of a terminal material should have low resistance to the electrical current flow. The assembly of the terminal is straight into the connector.

The silicon or rubber part has the basic function of insulate the systems against moisture. It is generally manufactured by rubber injection process in its various types and should include features to ensure a complete sealing.

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An automotive connection system has many applications in the vehicle, there being thus a variety of types, shapes, materials, among others. Its application is specific and can be used in different places and under different electrical and mechanical conditions as defined by Nicolas (2010).

2.2 Design for Six Sigma

According to El-Haik and Yang (2003), DFSS is a method dedicated to the product development process, through customer-oriented projects aiming as result products that usually reflect the needs and requirements of customers, is a response to the growing tendency of the improvement need in project performance. "The DFSS provides a systematic integration of tools, methods, processes and team members during product development, and a method of analysis in complex engineering system that uses statistical models to achieve customer satisfaction through better product that can be offered " as defined by Jugulum and Samuel (2008). The basic definition of DFSS can be summarized as a method applied to product, process or service development through dedicated tools, based on the customer needs, desires and expectations, focusing the complete customer satisfaction. Thus, brings a cultural change in the development process, from a deterministic to a probabilistic approach.

Edgeman (2003) explains that by applying DFSS method is possible to develop a more robust product through statistical and quantitative methods moving from a reactive, making and testing, to a preventive mode, with a balanced and optimized progression.

2.3 Design for Six Sigma versus Six Sigma

In a preliminary analysis it is possible to identify a similarity and proximity in between DFSS and Six Sigma methods, even DFSS looking like an extension of it Six Sigma. However, it should be noted that this is not the reality. Although the DFSS share many features that made Six Sigma a worldwide known method, they are independent methods. Six Sigma is a method typically applied in production and service processes that are in need of significant improvements in their results and performances. Through data collection and detailed analysis it is possible to identify statistically parts of the process that need improvement efforts and applying Six Sigma method tools, the overall performance improves.

The principle of DFSS is different; it is applied to develop a brand-new product, process or service. Ginn, *et al*., 2004 argues that although some of Six Sigma and DFSS steps and phases have similar names, there are distinct differences in the application purpose, results and method tools. Ginn, *et al*., 2004 also states that organizations must implement DFSS to design products, processes or services that do not yet exist or to improve products, processes or services that have not been developed to its current capacity, which does not meet requirements of multiple customers or have several versions.

According to George (2002), Six Sigma focuses on eliminating waste attacking not the product but the process in the factory as a whole. This consists of all existing activities within the company, including inspections, rework and scrap, but no change is made directly on the product. George (2002) further explains that Six Sigma is not able to overcome the five sigma level and based on that, DFSS is the way to achieve six sigma levels or higher, in this case the quality of product is designed and not only improved.

Fernandes (2010) complements the presented stating that the focus of Six Sigma is the process, but nonetheless the product is liable to changes based on the results of work done in the process, and the reverse is also true for DFSS when process changes are brought in by the focus on the product.

Ginn, *et al*., 2004 shows in Fig. 4 the integration between DFSS and Six Sigma methods and recommends its use in the beginning of the project to determine what approach had better to be applied.

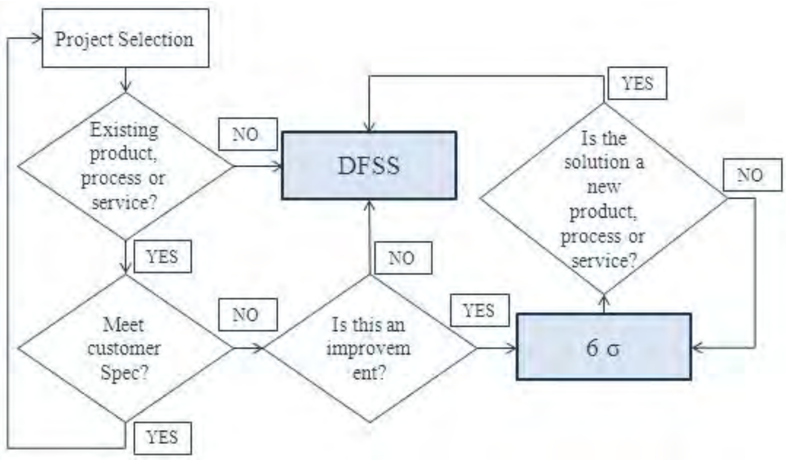

Figure 4. Method approach decision

2.4 Design for Six Sigma Structure

"The DFSS method aims the right product, at the right time and at the right cost, seeking customer satisfaction", as defined by Brue and Launsby (2003). It is understood in this study as right product a connection system with locking force (lock) suitable to the customer requirements thus translating the voice of the customer (VOC) in search of better performance for the product application.

As previously shown, the DFSS can be defined as a method with a rigorous approach to the development of products, processes or services and in the scope of right product at the right time, it aims to reduce delivery time, to reduce development cost, increase efficiency and effectiveness of development work and with the main focus in the customer, meeting their requirements, specifications, and desires.

Just like the Six Sigma, the DFSS presents a toolset capable of providing tangible benefits, as an excellent mechanical performance exceeding customer expectation, besides, obviously, overcome many of problems that cause failures in new products. As argued by Brue and Launsby (2003), is necessary to be cleared up that besides the DFSS presents many diverse tools, it is more than anything a method and not a strategy, and being a method, has the strong characteristic of phase structure.

According to Ginn, *et al*., 2004, the core of DFSS method is the division of activities in phases for development and some models and versions possible are the DMADV (anachronism of Define, Measure, Analyze, Develop and Verify) , IDDOV (anachronism of Identify, Define, Develop, Optimize and Verify), DMADOV (anachronism of Define, Measure, Analyze, Develop, Optimize and Verify), DMCDOV (anachronism of Define, Measure, Characterize, Develop, Optimize and Verify) among others, being DMADV and IDDOV the well-known between the existing.

Werkema (2002) present that the DMADV model is used by companies like GE, Faurecia and Seagate and that DMADV model closely resembles to the IDDOV model, being chosen the last one in this technical work because it is quite a didactic model of widespread use in companies like Delphi, GM, among others. The IDDOV is also composed of five steps, at a summary level shown in Fig. 5, with the division of activities exposed by Werkema (2002) with clear and specific goals.

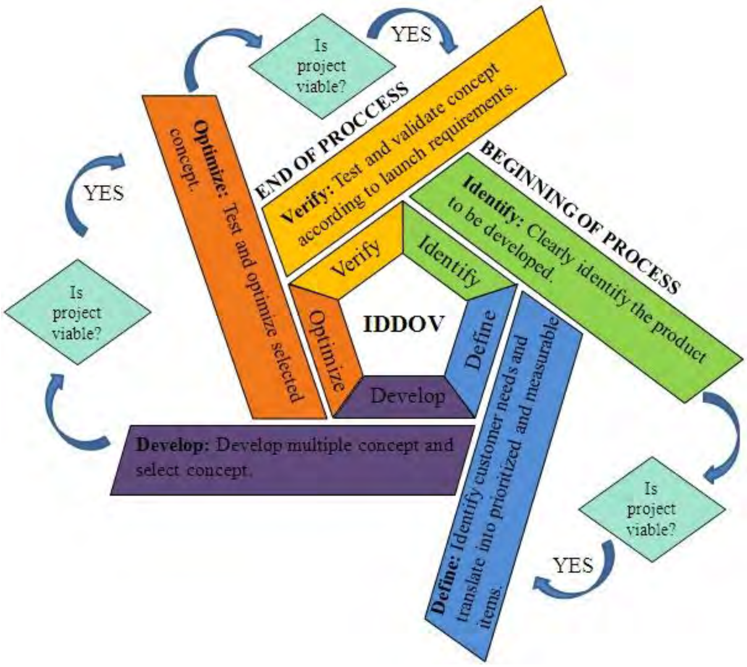

Figure 5. IDDOV model of DFSS method

The Identify, Define and Develop phases provide the tools necessary to evaluate and select the best concept among multiple concepts generated, including mapping the voice of the customer and the defining measurable elements linked to it. Optimize and Verify phases provide tools aiming a technical detail to the selected concept and an optimization for product robustness, meeting or even exceeding the initial requirements of the project.

2.5 Design for Six Sigma deployment

"Being a proactive method, DFSS considers the best techniques for preventing problems in the early stages of the development process, with a strong focus on the voice of the customer, voice of business, understanding the function of the product, modeling and forecasting performance, robust engineering , manufacturing capacity and management of change " as defined by El-Haik and Yang (2003).

Figure 6 illustrates a work flow structure based on the IDDOV model of DFSS method. In Identify phase is where the project starts and aims to mount people in a multifunctional team and understand the VOC. After VOC map start the phase Define, in which the scope of the project is worked and VOCs are translated into measurable and tangible items to the customer, the Critical to Quality (CTQ), and after this definition is begun subsequent phase, the phase Develop. In phase develop ideas and several concepts are generated to meet customer needs and among these developed concepts one or at most 3 concepts are selected (El-Haik and Yang, 2003), based on CTQs and reliability estimates. With the concept selected the Optimize phase begins, aiming to improve the idea and concept selected, assessing robust engineering definitions as well as manufacturability and process and product capability. At the end applies check and control tools of Verify phase, where the final results are evaluated against customer needs.

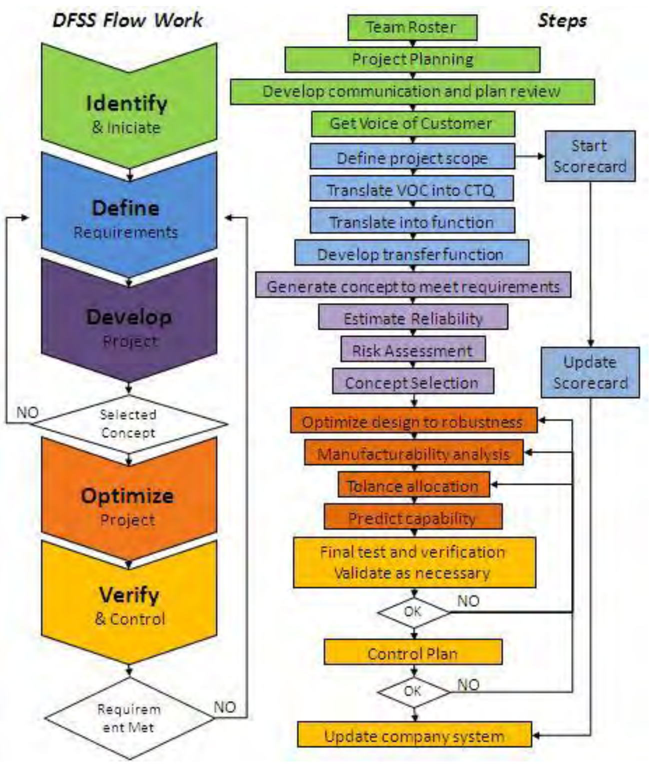

Figure 6. DFSS workflow

3. METHODS AND PROCEDURES

Considering the theory of DFSS and having the locking force as the highest CTQ priority in this project analysis, was studied an automotive connection system in order to achieve customer requirement in the Optimize phase through optimization process and tools. As per Brue and Launsby (2003), in this phase the goal is to refine the chosen concept, or even the chosen concepts, based on the detailed development design. For this study the purpose and final goal is to improve the concept of selected connection system lock and adjust it dimensionally seeking to make it as robust mechanically as possible meeting customer requirement and in the mean while reducing package.

After concept selection and qualification, was used the rapid prototyping tool with Selective Laser Sintering (SLS) technology through the machine 250 SLS obtaining physical models with similar characteristics to the final component. The material used in the prototype parts has mechanical characteristics equivalent to the original material of the component to be representative in selected concept evaluation tests.

The main statistical tool used was the Design of Experiments (DOE) with a full factorial experiment for the three factors under study (three basic dimensions of the connection system lock) in its two levels (minimum and maximum), in this way analyzing the cause and effect relations in between the factors feeding back the concept design.

The prototype parts were submitted to tensile tests on a universal testing machine equipped with a load cell of 100 N, digital display and storage unit Microsys Dell® and the results of the maximum retention forces in newton were recorded for further investigation. Following, using the results of tensile tests performed on prototypes was applied statistical concept of response optimizer aiming to reduce the size to a minimum while maintaining the requirement of retention force, thus optimizing both the retention force and the package (dimensional), resulting a robust design in mechanical performance. All experiments were designed and processed using the statistical software Minitab®.

The function to be optimized is the mechanical performance, the restrictions are the lock dimensions measured in meters and the requirement is the retention force measured in newton.

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The selected dimensions for optimization are shown in Fig. 7. The selected requirement for the study was the retention force. Switching the three factors in its two levels (dimensions A, B and C in minimum and maximum) was analyzed the leverage over the retention measurements.

The values of the base width, thickness and length lock dimensions, represented respectively by A, B and C in Fig. 7, were replaced by the level values +1 and -1 (DOE coded), meaning that their absolute values are replaced by equivalence scale by taking their maximum and minimum in a simple linear transformation.

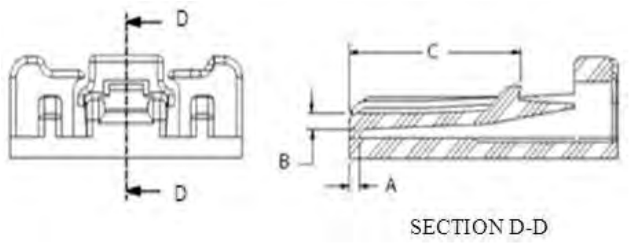

Figure 7. Connector lock dimensions

It is common to apply full factorial DOE when there are up to 5 input factors set at two levels each called maximum and minimum or +1 and -1. With the full factorial experiment application for the three factors involved in its two levels, were generated 8 rounds of tests (2^3), in this case, to increase the accuracy of the result were applied a replica for each round of testing, generating in this way 16 experimental conditions. Tests were performed following the standard order proposed by the statistical software in order to simulate randomness.

4. RESULTS AND DISCUSSION

The test results were recorded and are shown in Tab. 1.

Table 1. Experimental DOE measurements based on connector lock retention force

Test Number	Run Order	Dim. A	Dim. B	Dim. C	Measurement (N) Response Y
1	15	-1	-1	-1	20
2	6	1	-1	-1	21
3	1	-1	1	-1	25
4	10	1	1	-1	26
5	8	-1	-1	1	40
6	7	1	-1	1	41
7	3	-1	1	1	45
8	11	1	1	1	46
9 (replica)	13	-1	-1	-1	22
10 (replica)	14	1	-1	-1	19
11 (replica)	16	-1	1	-1	27
12 (replica)	4	1	1	-1	25
13 (replica)	12	-1	-1	1	42
14 (replica)	2	1	-1	1	43
15 (replica)	9	-1	1	1	44
16 (replica)	5	1	1	1	47

The tests results were used in the DOE aiming to understand each factor effect in the response, in this case the retention, getting as a graphic result a Pareto chart showing the effects over the response (Y) as shown in Fig. 8 and a second graphic result presenting the interactions between the factors, shown in Fig. 9.

Can be identified by the graph shown in Fig. 8 that the most relevant factors to the retention force and with p_values smaller than 0.05 (ANOVA table) are the factors B and C and that the interactions of second and third order have insignificant effect.

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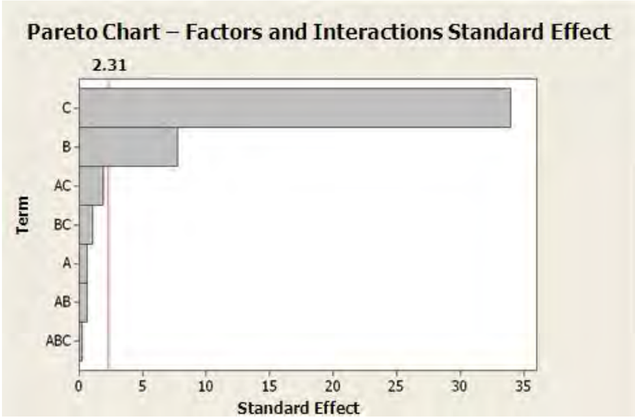

Figure 8. Factor effect in response

Based on the measurement mean is presented in Fig. 9 the result of factor interaction, confirming its small influence in the response (Y) measured in newton. Through a final analysis of the results and graphics, it is possible to conclude that the most important factors in this project are the dimensions C and dimension B, being the dimension C the one with the largest effect. All other terms had no significant effect on response.

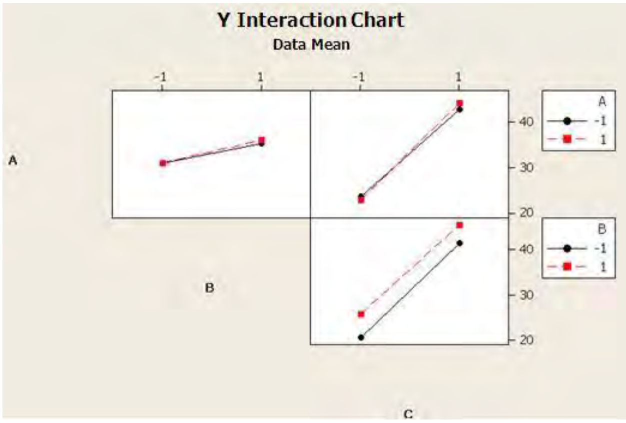

Figure 9. Factors interaction in the response

Working on the dimension optimization based on the target retention values, lower limit and upper limit (32 N, 30 N and 34 N respectively) defined in the Define phase of DFSS, and aiming the maximum optimization of the dimensional factors and therefore the improved performance, were used the response optimization function of Minitab® Statistical Software. By defining the limit specification and based on the responses Y (in newton) from dimensional factor levels variation (in meter), obtained from the preliminary presented tests, Minitab® uses a numerical procedure that seeks to meet in conjunction lowest possible value level simultaneously with the maximum response factors of interest. The proposed optimization generated is shown in Fig. 10.

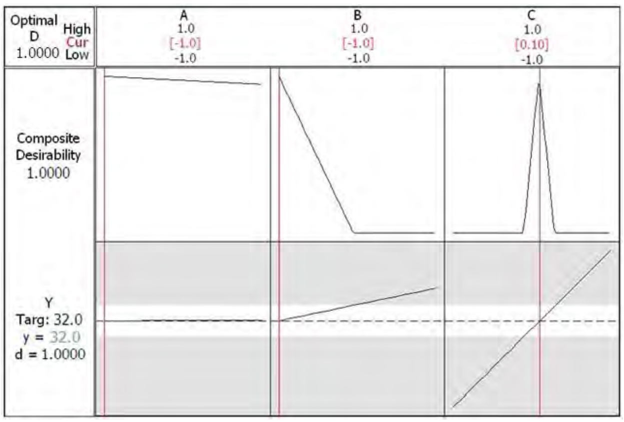

Figure 10. Response optimization proposal

With the analysis of the proposed optimization generated, it appears that the dimensions A, B and C must be, on a scale from -1 to +1 on a simple linear transformation, -1, -1 and 0.1 (coded) respectively for that the set retention value be reached, obtaining a robust product.

The concept has been modified based on the result of the optimization and new prototype samples were produced under the same conditions of material and process of early prototypes for further testing. The results of measurement tests performed on optimized prototypes are shown in Table 2.

Table 2. Retention force measurements (response) based on optimized lock dimensional concept proposal

Retention force in newton (response Y)			
33.1	32.1	32.4	33.5
32.3	32.2	33.0	33.0
32.5	32.8	32.4	32.7
31.9	32.9	32.8	32.6
32.7	32.4	33.1	33.0

A final confirmation in terms of product and process is recommended in the last phase of DFSS, the Verify phase. The results of optimized product tests are used in a capability function from the statistical software where it makes possible an understanding of the ability of the product dimensionally optimized to meet the requirements and specifications of the customer, in this case the functional CTQ more impacted by varying the dimensions is the retention force. The results are shown in Fig. 11, where it is possible to evaluate the capability of the studied lock based on the response of the retention force after dimensional factor A, B and C optimization. Through control charts I Chart, Moving Range Chart and Last 20 Observations, it is possible to observe the behavior of the response Y for the 20 prototype samples analyzed, being presented graphically in order to understand whether the product is in control state in its individual results, the variation between measurements and their absolute values, respectively (El-Haik and Yang, 2003).

The histogram and the normal probability plot show graphically a verification of the response Y and its normal distribution compared to the specifications.

By the Cpk value (potential capability index) it is presented an indication that a product or process is under control and can consistently reach the specifications. The Cpk represents the theoretical sigma level for the product, being ~ 3xCpk.

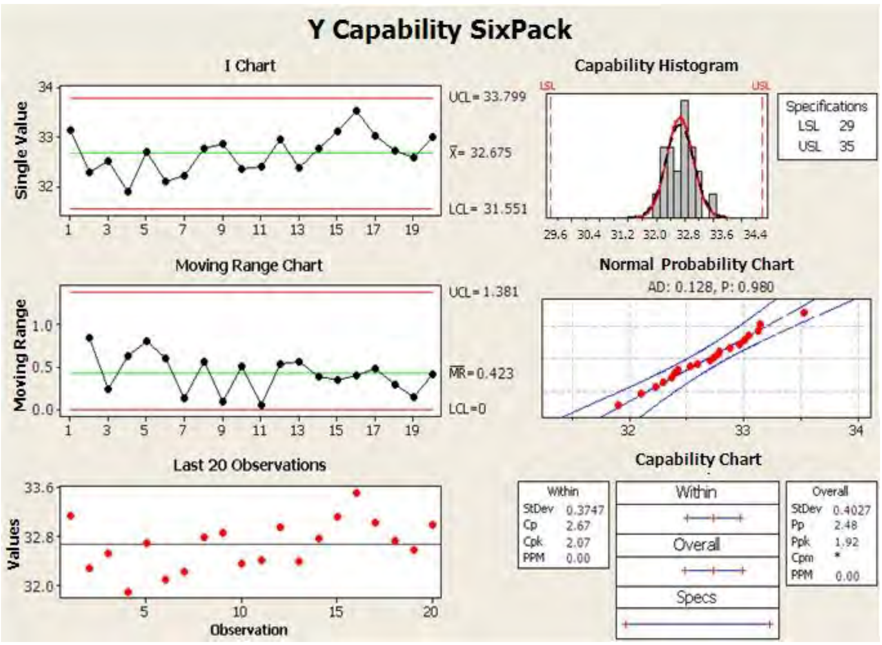

Figure 11. SixPack capability

Based on the measurements it can be seen through the graphs that the product is able to meet customer specifications, in this case defined as the upper and lower limits (35N and 29N, respectively). The product was designed to meet more stringent specification limits, thereby protecting the customer in performance. With Cpk value equal to 2.07 it is possible to state that the product, in this CTQ analyzed, is virtually six sigma.

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For the final result is given in Fig. 12 the automotive connector system lock optimized to meet customer requirements.

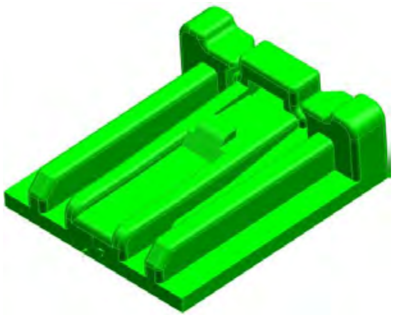

Figure 12. Optimized connector lock

5. CONCLUSION

Considering the global industries trend and the real need for high performance automotive components, the automotive engineering has tools available, technical and intellectual capacity to develop innovative solutions that meet customer requirements and is aligned in the best trade-off between better performance, assertiveness and development time. The DFSS method is an enhancement of the current enterprise product development process and not a substitute in which the company provides the product development flow and the DFSS provides tools and techniques so that the development can be done in an efficient way.

This study met its initial proposal for implementing DFSS in product development focusing on improving the performance of locking feature and ensuring in its final phase, virtually and statistically, that the product developed will meet the requirement and will reach six sigma levels.

For most organizations, the long-term success is directly linked to the process of development and alignment of these products to market trends. It is clear therefore that the DFSS can serve as a mechanism to revolutionize the way of developing new products with a focus on the customer and the market. The size of the effort is great, but the reward will not be lower than the company's survival.

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