International Journal of Engineering & Technology, 5 (3) (2016) 83-91

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v5i3.5898
Research paper

Efficient manufacturing of automobile spark plugs : A six-sigma materials re-engineering case

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Abstract

The processing defects of an World-class spark plugs-producing company are described, in terms of the Technology Management challenges involved. The full analysis of this complex situation, which involved 3 plants within the same factory, in terms of a Six Sigma approach, is explained, as well as the simple rengineering proposal, which led to an improvement from 2.47 Sigma to 5.32 Sigma in some specific cases, along with significant savings due to less product rejection and waste material..

Keywords: *Six-Sigma; Re-Engineering; Automobil Industry; Spark Plugs; Niquel Alloys.*

1. Introduction

According to The Society of Automotive Analysists, over 56 million automobiles are produced each year, which implies, for new vehicles alone, over 280 millon spark plugs, which requiere several tons of alloy 522, a nickel-based alloy, which is the main material for producing the electrode of those important ignition devices, due to its physical properties: corrosion resistance under gas combustión conditions, good processability at low temperaturas, excelent electronic emission and good heat and electricity conduction [1-7].

Today, the industrial manufacturing of spark plugs represents an important economical area, very intensive in terms of the resources, sales and technology involved. In spite that the details of each company are propieratory, Figure 1 provides a general view of the basic layout of a modern spark plugs factory, consisting, in general, of 3 correlated plants: ceramics, machining and assembly, each one interacting dynamically with the others, which represents an interesting challenge, from the standpoint of the technology management efforts requiered.

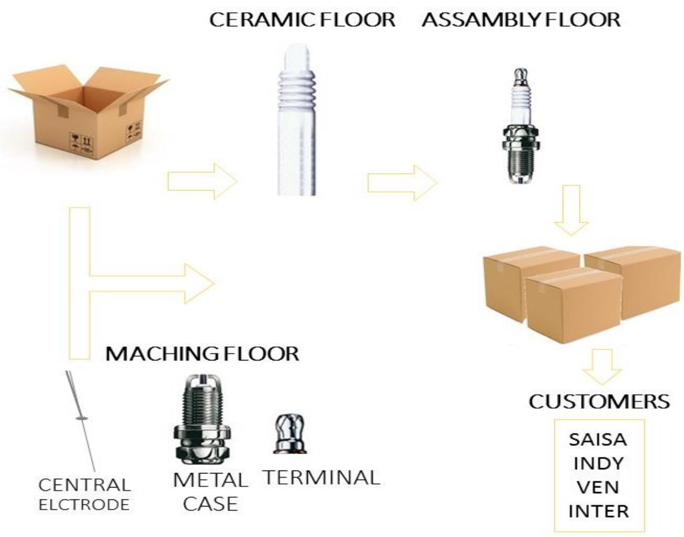

Fig.1: Schematic Diagram of the Industrial Production of Spark Plugs.

On the other hand, Motorola´s Bill Smith´s pioneer Six Sigma basic concept [8,9], which has represented a true revolution in the technology management area in the last few decades, is based on a rather simple concept: quality and performance problems are closely related to their own variability. Thus, the fundamental equation of this methodology may be summarized as:

Performance = 1/ variability

This simple relation then led some Motorola´s managers, as well as other experts from various industries, among which one can recall the names of Robert Galvin, Joseph M. Juran, Dorian Shainin, Genichi Taguchi, Eliyahu Goldratt and Mikel Harry, just to mention a hanful of all who soon enough realized not only the relevance of this approach, but also enriched it with the powerful mathematical aid of statistics [10-12], which introduced to the Technology Management field concepts such as Process Statistical Control, Juran method, Planned Experimentation and other Advanced Diagnosis Tools.
Graphically, it is well known that the concept of Six Sigma is best understood as shown in Figure 2, where a typical Gaussian distribution is depicted, along with the area under the curve for Six times Sigma, the standard deviation of the statistical distribution. Mathematically, it can be demonstrated that the area under the curve for Two through Six times Sigma corresponds to 308537, 66807, 6210, 233 and 3.4 failures per million pieces, respectively, indicating the decreasing percentage of failure or variability of a specific property of characteristic of given product, as expressed by the plot.

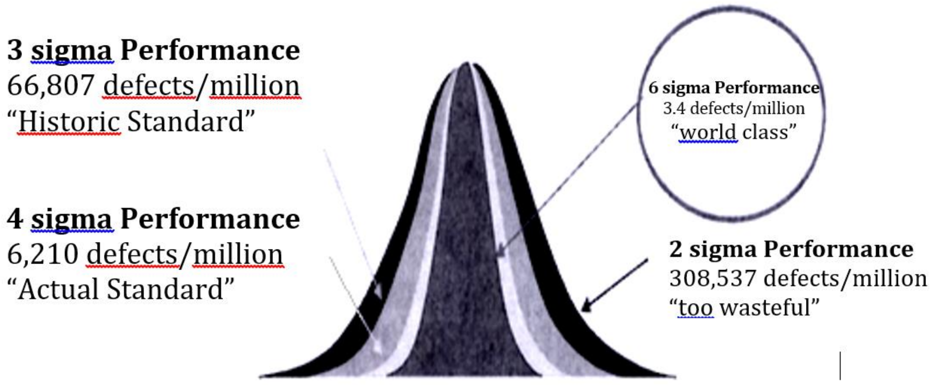

Fig. 2: Graphical Representation of the Six Sigma Concept in A Gaussian or Normal Distribution.

However, while introducing these management devices into Mototrola, Harry noticed that, no matter what was implemented inside the company, the achivable limit was Three Sigma, whereas For of Five Sigma was attainable once the suppliers chain was properly trained. Six Sigma was only achieved once the company had a better understanding of key concept such as robust design, systems design, parameters design and tolerance design, which, in turn, implies a numer of steps that nowadays constitute the core of the Six Sigma Methodology.
Accordingly, the purpose of this present article is to describe the technical limitations of an important, World-class spar plugs-producing factory, based in Mexico, with an important percentage of the production for the american and european markets which, in spite of great effort to decrease the technical variations to its products, which directly impact the performance of the automobiles in which those spark plugs were utilized, had little success, until a Six Sigma rengineering of the whole process was succesfully implemented, as shall be discussed in what follows.

2. The industry of automobil spark plugs: challenges and opportunities

Technically speaking, a spark plug fulfils many key functions in a internal combustion engine: from the adequate sealing of the combustion chamber, to the effective conduction of the spark generated in the coil, to the conduction of the heat generated towards the cooling system. All this implies a sophisticaded technology for producing effectively a rather humble-looking component of an automobil which, nevertheless, represents one of the key factor for mechanical, economical and even ecological performance of one of the icons of modern society.
In broad general terms, a spark plug consists of 3 fundamental components, namely, the metal case, the insulator and the electrode, as shown in the diagram of Figure 3. The metal case is an hexagonal piece, whose dimensions are strictly regulated the the SAE and the ISO, which leads to the use of cold-rolled steel to be able to meet the dimensional specifications, along with some high-tech coatings to reduce corrosion.

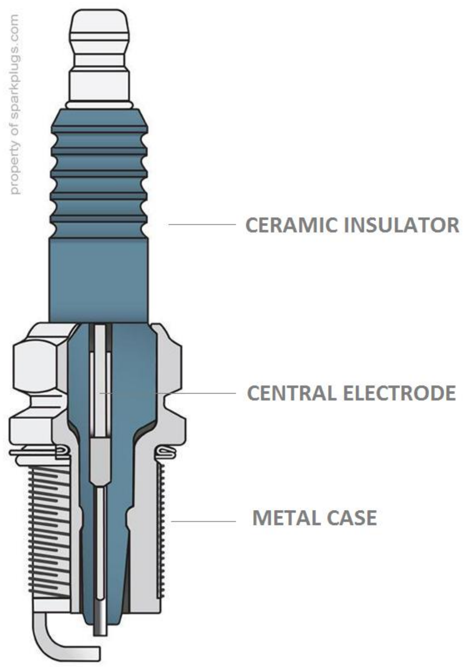

Fig. 3: Components of A Typical Spark Plug.

The insulators are normally made of zirconia-containing high grade alumina, which allows to produce a material with good thermal and electrical insulation behavior. Also, the physical design of this component is determinant for an efficient performance, since the roughness is produced on purpose to prevent undesired short circuits, which happens in cases where the quality control allows dimensional variations below the Six Sigma standards.
The third component is directly in charge of the introduction of the spark to ignite the fuel: the electrode. From the Materials

Science point of view, this is perhaps the most challenging one out of the three components, for the physical and chemical conditions of the combustion chamber demand a very special material, conditions which are only met, as mentioned above, by a nickel-based alloy, the 522. The nominal chemical composition of this important industrial produce is summarized in Table 1. A number of technologies have been proposed to expand the lifespan of the electrode, including precious metals such as iridium, platinum and gold-paladium alloys.

Table 1

Chemical composition of Alloy 522 (wt %)

C max	Si	Mn	Cr	Femax	Ni
0.05	0.06	2.0	1.8	0.5	94-95

Figure 4 shows graphically the steps of the Six Sigma process, as applied to the production of spark plugs.

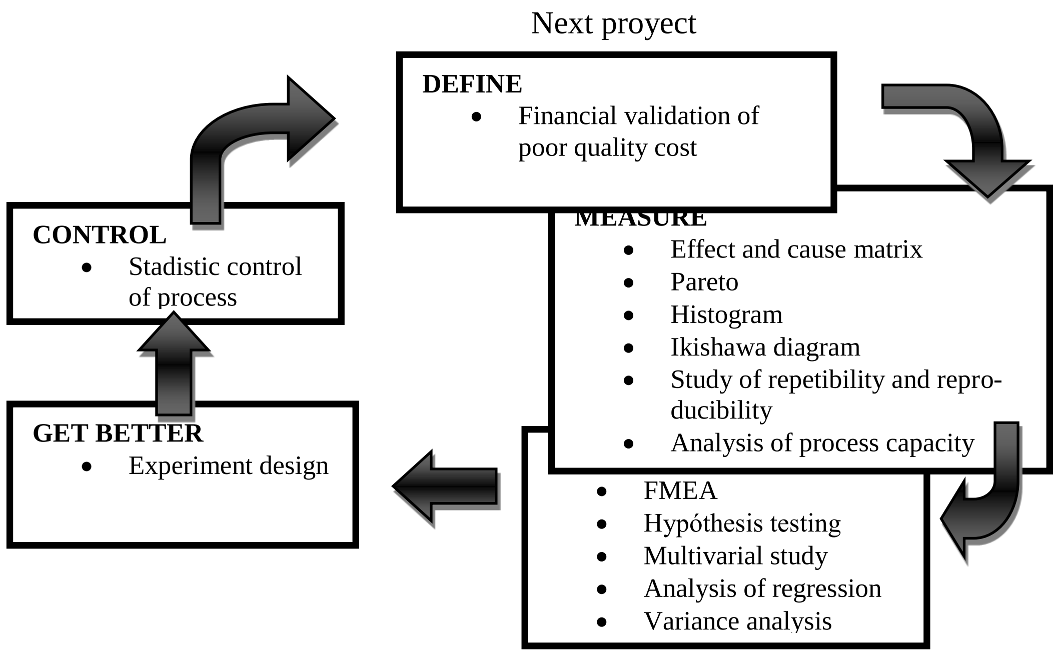

Fig. 4: Steps of the Six-Sigma Re-Engineering of the Spark Plugs Production.

3. Definition of the problem

From the production management standpoint, the electrode is one of the main sources for defects of different sorts, which directly impact the performance of the plug. As shown in Figure 5, the two main sources of defects in the pieces are broken starting tip or damaged electrode.

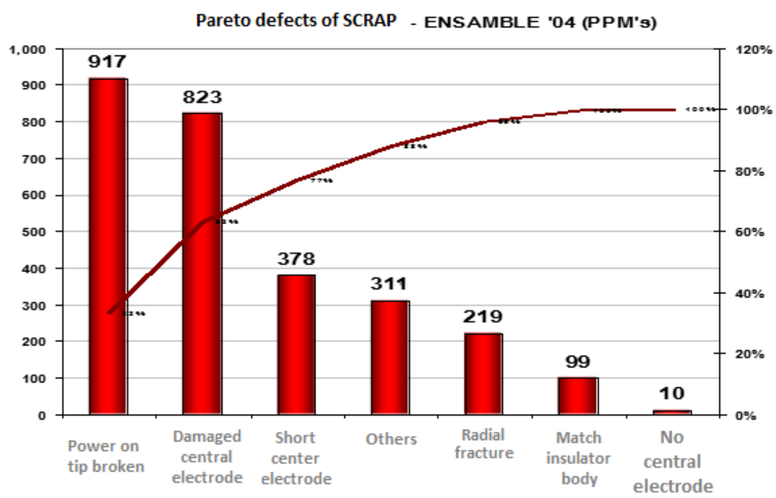

Fig. 5: Distribution of the Types of Defects in Spark Plugs.

This is true for all of the 6 types of spark plugs produced in the factory, as summarized in Table 2, where the acute problem with type 1 spark plugs is evident.

Table 2: Number of Defects per Each Type of Spark Plug Produced

PLUG TYPE	PIECES	%
1	1472	34.77
2	959	22.66
3	731	17.27
4	472	11.15
5	326	7.70
6	273	6.45
total	4233	100

This serious production problem represents a true technology management challenge, for the broken starting tip is a combination of problems in the 3 plants of the factory (see Figure 1). Physically, this problem can be appreciated in the photograph of Figure 6, where the broken tip causes a number of technical problems, highly detrimental to the performance of the vehicle and which appears in all 6 different types of plugs, but mainly in type 1, as shown in Figure 7.

Fig. 6: Photograph of a Broken Starting Tip in the Plug.

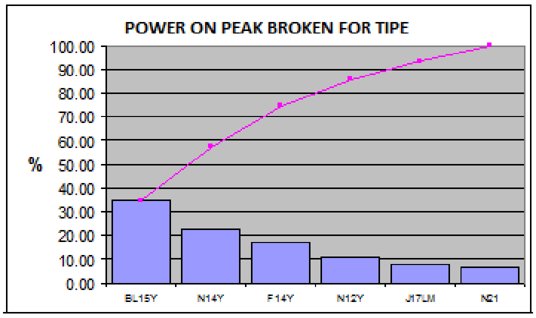

Fig. 7: Distribution of Broken Starting Tips per Each Type of Spark Plug.

The economical impact of this tiny little defect is summarized in Figure 8, per each 3 months period of year 2003.

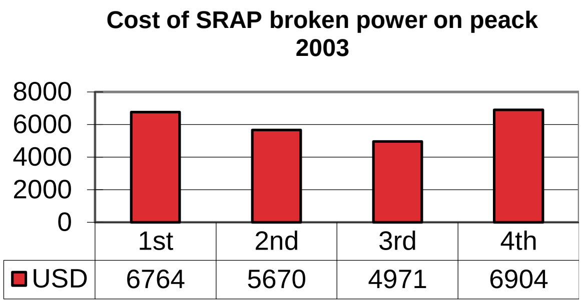

Fig. 8: Cost, Per 3 Month Periods, of the Losses Due to the Broken Starting Tip Defect, for Year 2003.

Due to the multifactorial nature of this problem, a multidisciplinary team was organized to manage the technological approach to follow. The team was formed by 3 technicians, each representating each of the 3 plants, 2 members of the quality group of the company and the 3 managers of each plant.

4. Measurement

To be able to identify and measure the various stages of the problem, Figure 8 shows the mapping of the whole process where the failure was detected. The trimming station and the pilot cell, where the renigineering project will be focused, are pointed out in the diagram. The Critical To Quality inputs and outputs of the system are summarized in Figure 11, along with the relative weights for each parameter, as evaluated by the team [13-16]. As it can be observed there, the highest weight (64 points) was given to the trimming station, which explain the reason to focus the renginering efforts precisely there (see Figure 9). It must be pointed out that all the failure analysis were carried out according to the FMEA and AIAG standards [15-18], which are accepted and followed worldwide. Figure 12 corresponds to the Pareto analysis of the cause effect matrix.

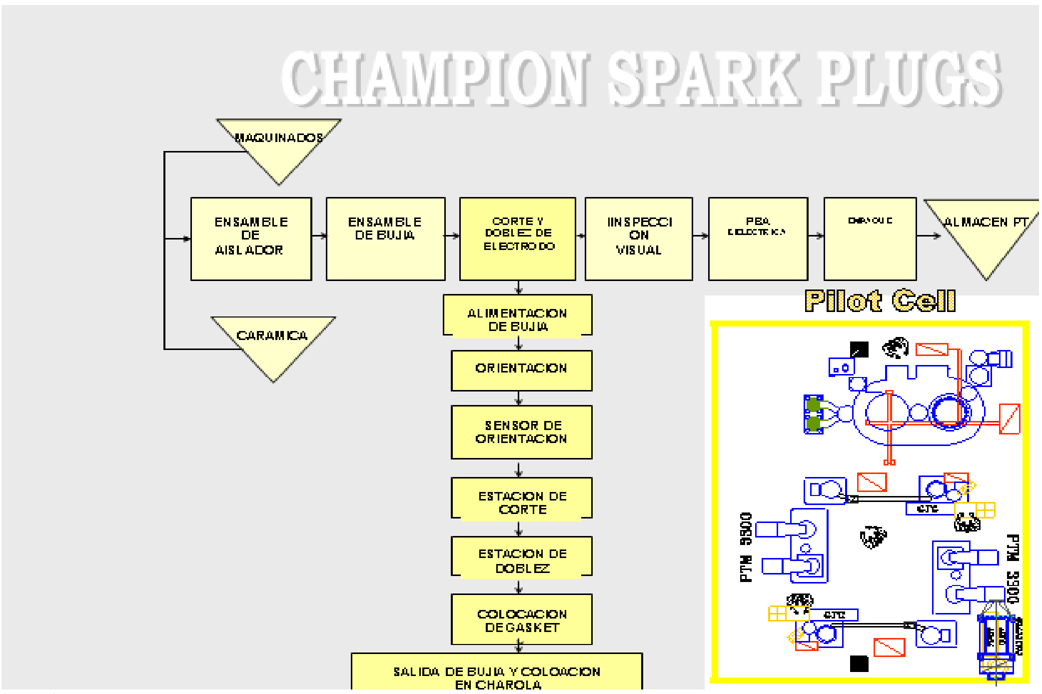

Fig. 9: Map of the Processing, Pointing Out the Trimming Station and the Pilot Cell, Where the Re-Engineering Project was Implemented

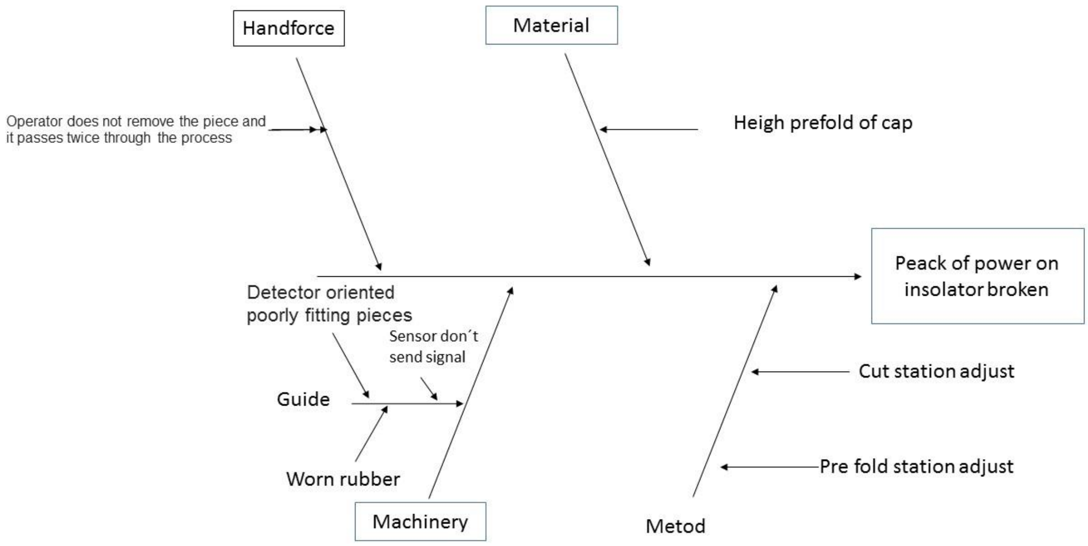

Fig. 10: Fishbone Diagram to Determine the Root Cause of the Problem.

QUIALITY CRITICS

	OPERATION	CTQ´S VARIABLE X'S	REVIEW	CONTROLLABLE	NOISE	CONCURRENCE	Y= BROKEN SPIKE 8 NPR
IWA	1 SUPPLY ISOLATOR	SUPPLIER OF ORIGIN			X	3	24
		LOAD TRAY WITH MORE THAN TWO	X			2	16
		LACK OF PROTECTION IN THE BOWL	X			5	40
	2 CENTRAL ELECTRODE SUPPLY	N/A					
	3 TRANSPORT RTW1	ADJUSTING THE THROTTLE INERT AGAINST HEIGHT	X			2	16
	4 BOUND	ADJUSTING OF RTW2 VS HEIGHT OF INSERT IN OUTPUT	X			2	16
	5 TRANSP .RTW2	N/A					
	6 PLACE TERMINAL RSC	MISADJUSTMENT OF RUBBER ALLOWING THE FALL OF ISOLATOR		X		4	32
		HIT TO THE CARS OF SPRING-CARBON TO INSULATOR		X		1	8
		PRT BEAT A POINT POWER ON OF INSOLATOR	X			2	16
	7 TRANSP .RTW2	HITTING THE CONTINUITY TEST ON A POINT (IT FANS OUTSIDE THE BOX)		X		2	16
	8 LIFT CONE	N/A					
	9 RHYMED	N/A					
	10 CLOSED FALANGE	PRESSURE EXCESS			X	3	24
	11 RELEASE ARM	ADJUST OF ARM AND DISC		X			
	12 PLUG DOWN	VELOCITY ADJUST OF ARM			X	3	24
	13 DROP A TRAY	N/A					
GTG	1 PUT TRAY ON TABLE	SPARK FREE FALL IN WORKSHOP ASSEMBLED			X	2	16
	2 ORIENTATOR	N/A					
	3 SYSTEM OF REJECTION	N/A					
	4 CENTRAL ELECTRODE CUT	HEIGHT ADJUSTMENT OF CUTTING STATION		X		8	64
		BAD ORIENTATION OF SOARK PLUG		X		6	48

Fig. 11: CTC and Cause and Effect Matrix.

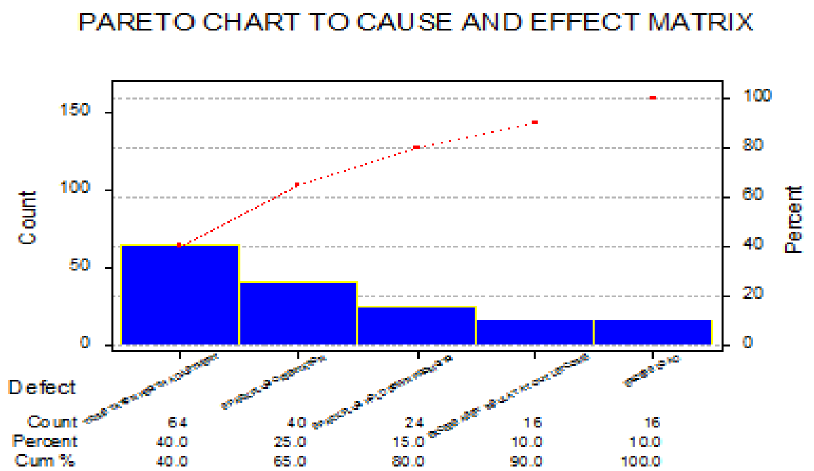

Fig. 12: Pareto Chart to Cause and Effect Matrix.

5. Analysis

Figure 13 corresponds to an schematic layout of site in the assembly plant where the Six-Sigma rengineering process was implemented. From the Pareto analysis, an experiment design was followed, by using the cofactors method [17], [18] and each batch included 120 spark plugs.

Table 3 contains a summary of the hypothesis and development of the experiment design. The idea was to set an strict control of the cut height under Six Sigma standards.

Linear regression of the data obtained experimentally are summarized in Table 4, whereas Figure 14 shows the regression equation obtained along with the analysis of the data, from which one can conclude that, since its probability is lower than 0.05 the alternarive hypothesis Ha can be rejected and then ensure, with a 5% probability of error, that a wrong adjustment of the trimming station indeed causes the broken starting tip.

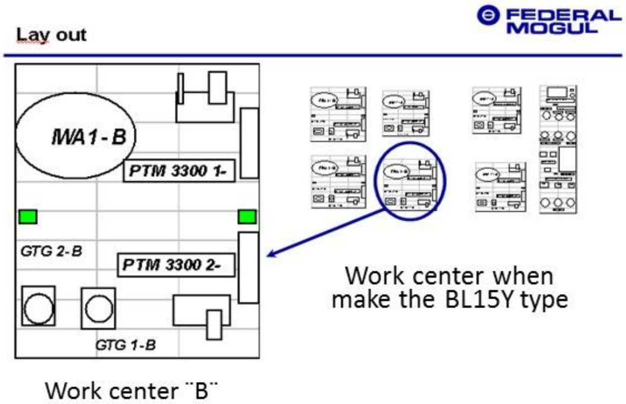

Fig. 13: Layout of the Site in the Assembly Plant where the Six-Sigma Re-Engineering Process was implemented.

Table 3: Experimental Design

Ho =	Adjusting the cutting height Power generates broke peack					
Ha =	Adjusting the cutting height Power that no generates broke peack					
DATA TYPE						
Y =	% from broke peak power			(continue)		
X_1 =	Heigth cut Adjust			(continue five levels)		
	X_{11} =	4.600	in			
	X_{12} =	4.650	in			
	X_{13} =	4.700	in			
	X_{14} =	4.725	in			
	X_{15} =	4.750	in			
TOOL TO USE						
regression analysis						
SAMPLE SIZE		120 Piezes lot				

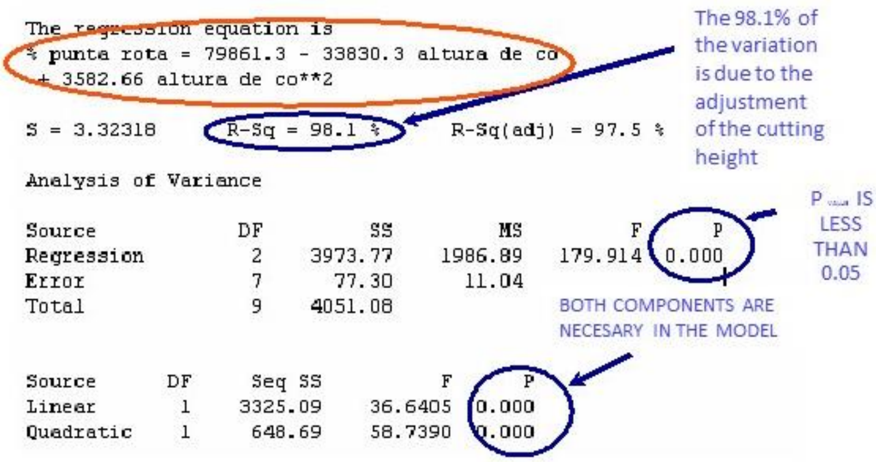

Fig. 14: Summary of Linear Regression Analysis of the Experimental Data.

Table 4: Linear Regression Analysis of the Experimental Data

C1	C2	C3	C4	C5	C6
CUT HEIGTH	%BROKE peack	RESI 1	FITS 1	RESI 2	FITS 2
4.600	49.16	6.9630	42.1970	-1.91646	51.0765
4.650	20.00	-5.2664	25.2664	3.45858	16.5414
4.700	0.83	-7.5058	8.3358	0.91034	-0.0803
4.725	0.00	0.1295	-0.1295	1.67373	-1.6737
4.750	0.00	8.5948	-1.21119	1.2112	1.2112
4.600	54.16	11.9630	42.1970	3.08354	51.0765
4.650	10.0	-15.2664	25.2664	-6.54142	16.5414
4.700	0.00	-8.3358	8.3358	0.08034	-0.0803
4.700	0.00	0.1295	-0.1295	1.67373	-1.6737
4.725	0.00	8.5948	-8.5948	-1.21119	1.2112

Therefore, the renginnering efforts must be focused to the GTG trim station, responsible for the process causing the failure.

6. Improvement

Figure 15 shows the original process, around which the failure occurs (lefthand side) and the proposed method (righthand side), based on the statistical analysis, along with an actual pothograph of the trim station (center of the figure), which is basically the core of the new proposal: the removal of such station.

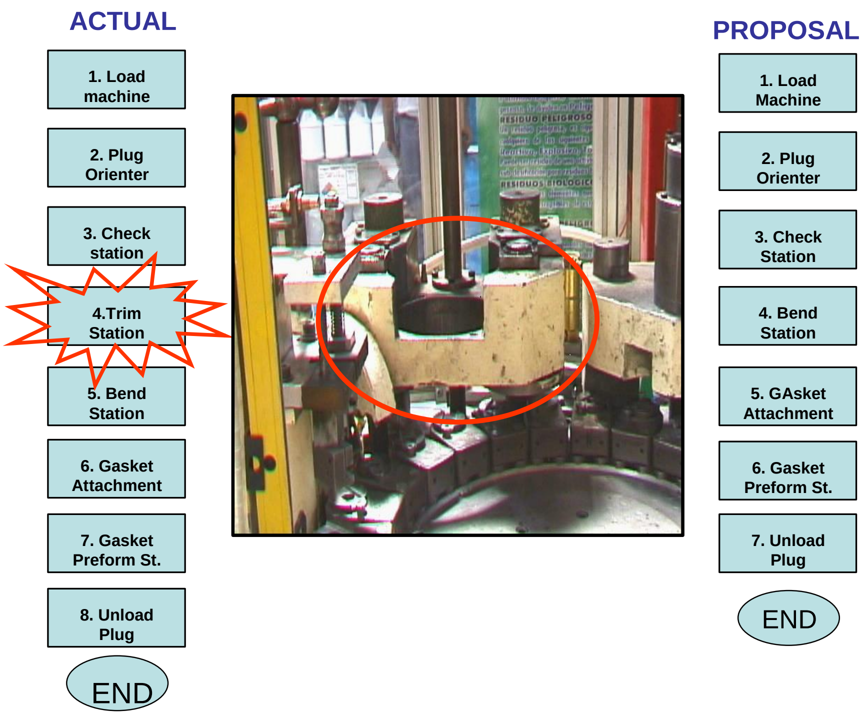

Fig. 15: Rengineering of the Process: Original (Left) vs. Proposed (Right) Methods, with A Photograph of the Trim Station (Center).

However, eliminating the trim station implies a redesign of the components itself and a full rengineering of the concept of the process itself. Technically, the idea is to bend the central electrod to obtain the proper gap, instead of trimming it, which was, as explained above, the root cause of the problem. This obliges to a very strict dimension control to ensure that the bending will the exactly the same for all spark plugs produced. A Pareto analysis (Figure 16) leads to conclude that the key dimensions to control were:

1) Height of the base of the metal case
2) Lenght of the central electrode
3) Depth of the of drill in the insulator

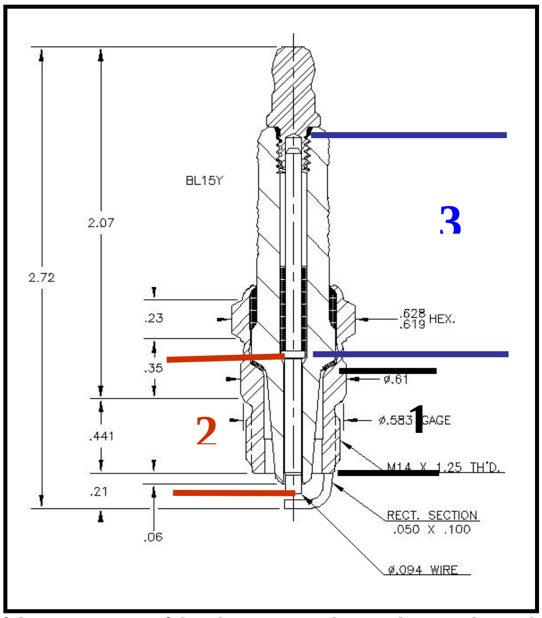

Fig. 16: Pareto Analysis of the Dimensions of the Plug to Control, in Order to Achieve the Re-Engineering of the Process.

As shown schematically in Figure 17.

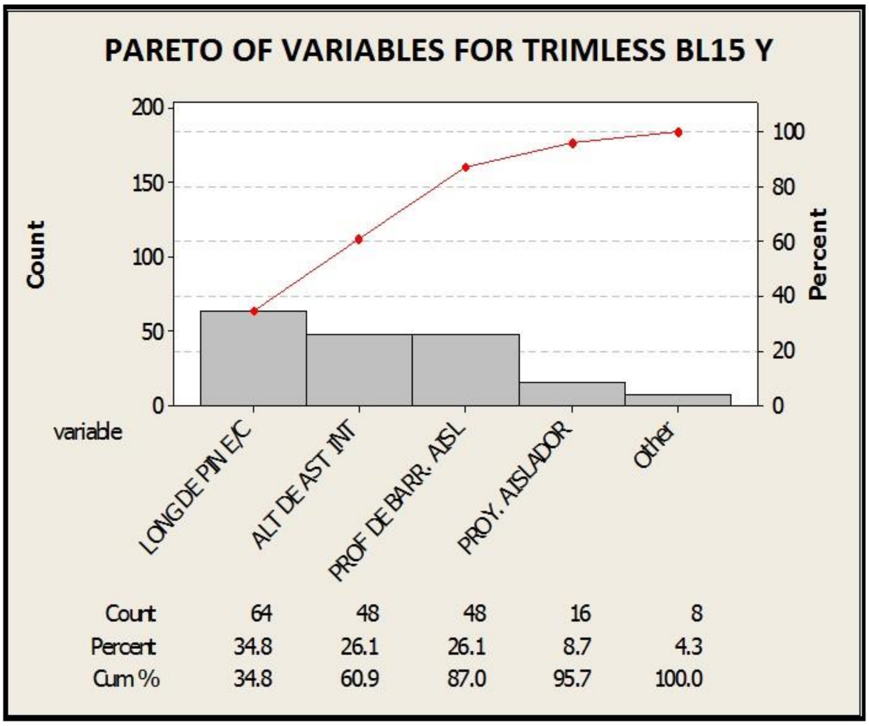

Fig. 17: Schematic Diagram of the 3 Key Dimensions to Control in the Spark Plugs.

Table 5: Statistical Comparison of Originals vs. Re-Engineered Technologies for Dimension 1 in the Spark (Figure 17)

	SITUACION	ESPEC (INCHES)	AVERAGE (INCHES)	SD (INCHES)	Cp	CPk	READING MAX	MIN	SIGMA
HEIGTH OF CUT IN	ACTUAL	0.118 - 0.128	0.1242	0.00135	1.24	0.93	0.1267	0.1215	2.81
SPARKING PLUG	PROPOSAL	0.118 - 0.128	0.1234	0.00114	1.46	1.35	0.1257	0.1207	4.04

Table 6: Statistical Comparison of Originals vs. Re-Engineered Technologies for Dimension 3 in the Spark (Figure 17)

	STATUS	SPECIFIC (PULG)	AVERAGE (PULG)	SD (PULG)	Cp	CPk	READING MAX	MIN	SIGMA
GAP	ACTUAL	0.033 - 0.038	0.0356	0.00097	0.86	0.81	0.0380	0.0337	2.47
ASSAMBLED SPARKING PLUG	PROPOSAL	0.033 - 0.038	0.0356	0.00032	2.57	2.47	0.0363	0.0349	5.32

Then, a test, consisting of 500 plugs, was carried out, to statistically asses the feasibility of this rengineering approach. Tables 5 and 6 contain a comparative summary of the original and rengineered technologies, for dimensions 1 and 3 (Figure 17) respectively, as an example (the situation with dimension 2 is very similar).

As observed there, for the case of dimension 1, the original technology allowed 2.81 Sigma, and the new approach reached 4.04 Sigma. For dimension 3, the improvement was from 2.47 Sigma to 5.32 Sigma.

7. Control

After the improvement shown by numerous tests, the proper management of the technology developed requiered the design of a way to control, on day-to-day basis, the performance of the process. After an analysis of the culture and uses of the factory, it was decided to provide the operators of the different plants (Figure 1) with rainbow charts which enabled them to check on line the dimensions obtained, along with a report form which was distributed among all the participants and allowed to follow, almost on line, the progress of the production.

8. Conclusions

The broken starting tip defect was reduced 95% with respect to the original approach, by the rengineering described, for spark plug type 1, which was the plug with the highest incidente of defects. The elimination of the trimming station, from the point of view of the technology Management, allowed to reduce the number of critical parameters to only 3, which are the dimensions shown in Figure 17. This allowed to improve the process from 2.47 Sigma to 5.32 Sigma, and also to significantly reduce costs, not only due to the low incidente of defects, but also due to the elimination of a costly trimming process and the savings in waste of alloy 522, the main, and most expensive, component of the plugs.

References

[1] I. Calliari, a, , M. Zanescoa, M. Dabalàa, K. Brunellia and E. Ramousa, Investigation of microstructure and properties of Ni-Mo martensitic stainless steel, Mater. & Design, 29, 246-250 (2008). http://dx.doi.org/10.1016/j.matdes.2006.11.020.

[2] Z.-L. Zhan and J. Tong , A study of cyclic plasticity and viscoplasticity in a new nickel-based superalloy using unified constitutive equations. Part I: Evaluation and determination of material parameters, Mech. of Mater., 39, 64-72 (2007). http://dx.doi.org/10.1016/j.mechmat.2006.01.005.

[3] Z.-L. Zhan and J. Tong, A study of cyclic plasticity and viscoplasticity in a new nickel-based superalloy using unified constitutive equations. Part II: Simulation of cyclic stress relaxation, Mech. of Mater., 39, 73-80 (2007). http://dx.doi.org/10.1016/j.mechmat.2006.01.006.

[4] S. Nemat-Nasser and W.G. Guo Superelastic and cyclic response of NiTi SMA at various strain rates and temperaturas, Mech. of Mater., 38, 463-474 (2006). http://dx.doi.org/10.1016/j.mechmat.2005.07.004.

[5] H. Sehitoglu, C. Efstathiou, H.J. Maier and Y. Chumlyakov, Hysteresis and deformation mechanisms of transforming FENACOTI, Mech. of Mater., 38, Issues 5-6, 538-550 (2006). http://dx.doi.org/10.1016/j.mechmat.2005.05.024.

[6] W. Friend, Corrosion of nickel and nickel-base alloys, John Wiley, New York City (1980).

[7] A.R. Burkin, Extractive metallurgy of nickel, John Wiley, New York City (1987).

[8] S. Chowdohury, The Power of Six Sigma, Dearborn-Kaplan Business, Chicago (2001).

[9] M. Hammer and J. Champy, Rengineering the Corporation: A Manifesto for Business Revolution, Harper Collins, New York City (2003).

[10] E. L. Grant and R.S. Leavenworth, Statistical Quality Control, Mass Market, Boston (2004).

[11] T. Yamane, Statistics: An Introductory Analysis, Longman, London (1973).

[12] A.H. Bowker and G.J. Lieberman, Engineering Statistics, John Wiley, New York City (2003).

[13] D.C. Montgomery, Design and Analysis of Experiments, John Wiley, New York City (2000).

[14] Design of experiments, Vol. 1: Taguchi Approach, Daimler Chrysler Internal Report (1997).

[15] Potencial Failure Mode and Effects Analysis, FMEA Reference Manual, AIAG (2002)

[16] Statistical Process Control (SPC), Reference Manual, AIAG (2002)

[17] H. Kume, Statistical Methods for Quality Improvement, Chapman and Hall, London (1992)

[18] R. Berrúm, M.Sc. Thesis (Mechanical Engineering), Universidad Nacional Autónoma de México, Cuautitlán (2009).