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FRACTIONAL FACTORIAL DOE PLANNING TO REDUCE INTERNAL REJECTIONS ON LEAK TEST OF A COMBUSTION ENGINE PRODUCTION LINE

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PRESENTATION

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Abstract. *This work was applied in automotive industry in order to improve the efficiency of the combustion engines production leak test by using a fraction factorial DOE (Design of Experiments). The application of the anaerobic seal is done by a robot dispenser, and the main goal of this work is to demonstrate the application of fraction factorial DOE to improve the inputs of the application and eliminate leak fails on production leak test on the combustion engines at "T-joint" from the intersection between cylinder head, valve cover gasket and front cap. The method applied is experiment and the software used to plan the DOE and analyze the collected data is the Minitab. The inputs considered by the team application were four as: hose temperature, panel temperature, robot tip distance, and robot speed, as a result the input with the most significant effect identified on the DOE analysis is the robot tip distance. outputs: 1 - leak rate on leak test – this output showed no significance when analyzed the results from the DOE because it does not consider noise factors as environment temperature and humidity; 2 – seal bead diameter – this output showed to be significant on DOE, and is directly related to the root cause, because the leak failed engines on production leak test are missing or with lack of anaerobic seal on the "T-joint".*

The main result of this fractional factorial DOE is the best set of input parameters which exceeded the target of 80% improvement and achieved zero leak on the "T-joint" between cylinder head, valve cover gasket and front cap. This shows that fractional factorial DOE is an efficient method to be applied on the industry to improve process.
Keywords: *Design of Experiments (DOE), Production Leak Test Leaks, Anaerobic sealant, Fractional Factorial, Automotive Industry.*

1. INTRODUCTION

The Brazilian automotive industry has passed by a huge transformation on recent year, which was necessary to adapt their structure in order to support the lower volumes and challenge the new competitors entered on the market. Due to this, it is necessary to become more efficient and effective on their production process searching for significant improvements in order to improve quality, increase productivity and keep competitive.

DOE (Design of Experiment) is a widely studied and applied statistic tool, which according to Barros Neto, Scarminio and Bruns (2007), it is common on industry the necessity to study various properties at the same time, which may be affected by a certain number of experiments, then using experimental planning based on statistical principles will allow the extract of the maximum usable information by doing a minimum of experiments. There are several approaches to deal with several factors, but according to Montgomery (2012) the correct one is to conduct a factorial experiment, which the experiment factors are varied together, instead of one at a time.

Due to the limitation of time and resources, on this project it will be applied the fractional factorial experiment, which according to Wu (2018) is the most widely used experiment method in design of experiment, and which the experiment data is processed through ANOVA usually, thus pointed out whether the factors are significant.

According to Kreuser and Schmatz (2013) the Formed-in-Place (FIP) are used to attend the required sealing performance of zero leakage and two types of sealants are frequently used such as: Anaerobic sealants and Room Temperature vulcanizing elastomeric FIP sealants. On this project was applied the anaerobic sealant, which according to Kreuzer and Schmatz (2013) these products are used to seal rigid flanges.

The Fractional Factorial applied on this project occurred on an engine production process in order to decrease leakages during production process found at the “T-joint” between cam cover, cylinder head and cylinder head cam cap due to anaerobic sealant application performance variation.

The case studied will present some methods applied in the Design of Experiment in order to reduce the experimental error, such as randomization and replication, as well as the fractional factorial method, which is applied in order to reduce the time and costs of the experiments on practice.

This research is justified by the need of improving process by demonstrating and acquiring more knowledge of the influence of each input and their interaction on process and configuring process with the best inputs set.

This work aims is to demonstrate the use of a fractional factorial DOE as an efficient method to plan the data collection of the critical inputs at different levels at the same time, and analyze the collected data to set-up process, in order to significantly decrease or even eliminate the defects of leaks detected in the process thru the “T-Joint” between the cylinder head, anaerobic seal bead, front cap and valve cover gasket.

2. THEORETICAL BACKGROUND

2.1. Automotive production line

According to Zhou apud T. Levitt (2017) the production service was proposed in 1972, and from that time, the production line was considered an important research area, and nowadays so many articles can be found related to this area.

According to Zhou et al (2017) a sustainable production line involves lower costs, good production environments, and green manufacturing, which requires that the line efficiency must be monitored and studies and experiments must be performed in order to continuously improve the line process efficiency.

According Zhou et al (2015) the traditional single production line has become the current hybrid production line. For Yan et al apud Gui (2015), a variety of type engines are produced at the same production line. Hence nowadays it is common to have a line which produces more than one type of product on the automotive industry, which becomes a challenge to achieve an efficiency on line for all products.

According to Bautista et al (2015) the flexible system in assembly lines are composed of cells, and modules, which are very common in production environments in the automotive sector as engine line. This requires different setups, process changes, continuous improvement, and problem-solving techniques at each manufacturing stage in order to guarantee the continuous production flow.

2.2. Research Contribution

The automotive production research has a great significance. Pandian and Ali (2015) performed an investigation of maintenance assumption for an automotive production line by using a simulation modeling for the welding assembly. Halim et al (2015) performed a case study to design a new storage system for an air cleaner by using computer aided manufacturing added design software, CATIA V5R20, and evaluated its effectiveness by using a computer aided manufacturing software, DELMIA Quest. Song et al (2016) proposed a new method of detecting cracks in an automotive stamping process, through the use of nondestructive, acoustic emission test.

More specifically inside automotive area the engine production research has great significance. Lalami et al (2016) performed an important real case study for production planning in powertrain plants. Bautista et al (2015) performed study of a mixed- model sequencing problem, resulting in an increasement of profits for the company was performed by. Yan et al (2015) performed a study of an automatic logistics system an engine production line. Another study performed by Zhou et All (2017) in an engine production line evaluating the sustainability of the production line.

2.3. Issues

According to Zhou et al (2015) many production imbalances were observed in the pursuit of higher profits, which affects production efficiency and cost, and these imbalances might be caused due to quality issues, machine capacity, machine downtime, and other issues.

According Zhou et al (2015) the rule of the production line is to conform to the order form, which is limited by the production amount boundary. Hence the line might be limited to its capacity, or by its quality efficiency, machines faults and downtimes, and other issues, which limits the production to attend a higher demand, and also generated wastes, increase cost and might impact on customer satisfaction.

According to Bautista et al (2015) when the resource usage depends on the product, e.g., in the product-oriented production systems, several problems can be found, and those problems might be related to line-balancing and batch, product-unit sequencing, and quality issues.

According Velandia et al (2016) in the automotive industry a large number of engine components are manufactured in-house, and some automotive manufacturers (OEMs) manufacture only the 5Cs, Cylinder block, Cylinder head, Crankshaft, Camshaft, and Connecting rod and purchase other components from suppliers, while other OEMs prefer to reduce the number to 3Cs i.e. Cylinder block, Cylinder head, and Crankshaft, which depends on the reliability of the supply chain and concentrates only the high value-added, critical, and high-technology operations which require high capital investments. The assembly, and tests on the engines are also in charge of the OEMs.

According Pandian and Ali (2015) the assembly plants are required to meet the daily shift production at the end of each shift, and if the production number are not met, workers are forced to work overtime at the end of the shift. This could be caused due to quality rejections, machine faults, and other operational issues which may lead the plant to not reach the target and generates a lot of waste on its production.

2.4. Solutions

According Song et al (2016) the ability to produce a high-quality product is critical in the automobile manufacturing industry, and also the ability to detect a flaw in products is required in order to guarantee high quality. Due to it is necessary to improve process thru working on its inputs in order to reduce the rejections on the detections and making process more reliable.

According to Zhou et al (2015) it is required the coordination of various products in the production line, and for Zhou apud Joo et al (2015) the analytical hierarchy process, and data envelopment analysis, require more detailed evaluation data. This means that it is always necessary to plan and collect data from the process to study and make decisions.

According Zhou et al (2015) the sustainability of the production line is influenced by many factors, and it is necessary to understand the combination of qualitative and quantitative methods to discover them. For Zhou et al (2015) to solve those issues, it is necessary the identification of the type of the underlying impact factors, uncertainty of the influencing factors, and incompleteness of the evaluation information. Hence it becomes extremely important to understand the relationship of the input factors which influence the output and chose the type of data to work with on the production lines.

According Yan apud Fang and Zang et al (2015) with the development of the large-scale and automated production lines, the automation became significantly important, and the advantage of automation consists of small footprint, saving manpower, high reliability and stability. Automation might be classified as essential in automotive production line, in order to become more competitive and efficient, which can be used to prevent failures to happen, in applications which requires a repetitive task with safety and ergonomic issues.

According to Halim et al (2015) to increase the market share and sustain in industry, most of the companies apply world class manufacturing techniques such as Lean Manufacturing, Toyota Production System, Just-in-Time (JIT), Kanban, Kaizen, Six Sigma and others. Hence it is necessary for the industry to have their people trained and capable to apply these techniques and the tools that compose them such as DOE.

2.5. Gasket and seal

According to Kreuser and Schmatz (2013) a gasket is a material between two flanges which are held together by fasteners, and its function is to prevent leakage of fluids or gases by completely filling the space between the surfaces of the flanges. The gaskets are applied in all areas of the industry and is essential on automotive and engine in so many different kinds of applications.

According to Sawa and Sasaki (1995) the first object of the connection is to increase strength of adhesions, then connections must be designed from a fail-safe standpoint, and the second object is to make two joint elements distribute an external load more efficiently by combining the adhesive joints merits and bolted connections. This is an important concept to zero leak joint gasket.

According to Kreuser and Schmatz (2013) it is necessary for the seal to remain intact and leak-free for a prolonged time. In the automotive area if the gasket sealing fails internally on the production tests or in the final customer, it will result in waste, additional costs, product poor performance, and impacting directly on customer satisfaction.

According to Kreuser and Schmatz (2013) seals are classified as static or dynamic, depending on whether the sealed parts move relative to each other, for example a rotating shaft in a housing is an example of a typical dynamic system.

According to Kreuser and Schmatz (2013) flanges are classified as static systems, and they encounter small “micromovements” because of vibration, temperature changes, shock, impact or transmitting loads.

In the automotive area Schuhmacher and Gotler (2007) states that the current and future engine developments in the commercial vehicles industry present extreme challenges for modern cylinder head concepts, and innovative solutions must provide custom designs combined with economical production even where relatively low volumes are required. This is a huge challenge for the gasket manufacturers, which must provide a high-quality product with more efficiency for the automotive process applications.

According to Kreuser and Schmatz (2013) static gaskets categories are shown on figure 1.

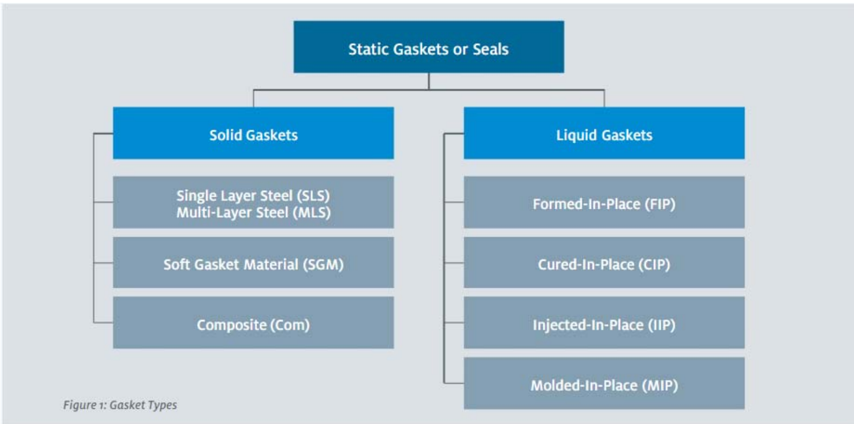

Figure 1. Categorization of static gaskets or seals (Kreuzer and Schmatz, 2013).

Formed-In-Place Gaskets

According to Kreuser and Schmatz (2013) FIP – Formed-In-Place Gaskets are formed by the application of a bead or by screen print of **liquid elastometer** or **anaerobic sealant**, which is assembled in uncured state, and on the assembly, the sealant spreads between the flanges and is forced into surface imperfections to provide total contact between the two faces, and then cures to form a durable seal. This type of application is nowadays very common on automotive industry due to demonstrate to be a good solution to avoid oil or air leakage.

For Kreuser and Schmatz (2013) the main advantages of solid FIP over solid gaskets are:

- **No gasket relaxation -** allow metal-to-metal contact in most applications, ensuring correct bolt tension throughout the life of the assembly, eliminating retorque;
- **Non-shimming** – metal-to-metal contact, eliminating the need for gasket thickness, and tolerances can be more accurately maintained;

- **Relaxed surface finish** – allow relaxation of surface finish and flatness tolerances, and then scratches and scored surfaces can be sealed without any repair of the damage surfaces;
- **Chemical compatibility** – demonstrate good to excellent solvent resistance;
- **Reduced inventory costs** – seals different flange geometries, without requiring the stock of many different gaskets to fit different geometries as solid gaskets.
- **Automatic application** – can be applied by a fully automated robotic dispensing;
- **Easier handling of vertical components** – can be applied to both horizontal and vertical flange faces;
- **Reduced hydrocarbon emissions** – as the seal gap is reduced, the hydrocarbon emissions are reduced compared to solid gaskets.

Anaerobic sealants

According to Kreuser and Schmatz (2013) anaerobic sealants cure in the absence of air and the presence of metals or other active surfaces. This is suitable for line process due to the line cycle time variation to close the cover part due line downtimes.

For Ryakhovskii et al (2015) anaerobic sealants A-501, AN-501 M, and AN-505 are used for rigid butt joint, where microdisplacements of conjugated parts with respect to each other should be minimized. This helps on filling gaps and results in a good sealing to avoid leakage.

For Kreuser and Schmatz (2013) these products are best suited to seal rigid flanges, and are designed to:

- Achieve optimum stiffness between two parts;
- Minimize movement between two parts;
- Transmit forces from one to another part.

Also Kreuser and Schmatz (2013) states that anaerobic FIP sealants are used for rigid bolted joints due to:

- Offering metal-to-metal contact;
- Ensure correct bolt tension;
- Maintain dimension tolerances accurately;
- Reduce micromovement and add structural strength;
- Easily disassembled by applying cleavage load to the joint;
- When sufficient load is provided offers a high pressure resistance;
- Offers extensive on-part life when exposed to air, making multi application methods possible, and reducing problems associated with volatile and/or moisture-cured

sealants.

For Ryakhovskii et al (2015) the advantages of liquid gaskets based on anaerobic compositions are:

- High curing rate;
- Stability of properties during long-term operation under sharp temperature drop and vibrations;
- High adhesion characteristics with a shear strength from 4 to 14 MPa;
- Good technological properties;
- Simplicity of application;
- Good corrosion resistant properties;
- Small Shrinkage in curing;
- Good wettability.

The experiment performed by Ryakhovskii et al (2015) concluded that if anaerobic sealant is used, the butt joint is more rigid when applied normal force, since metallic contact takes place of some parts of the joint surface. This resulted in a better seal when combined with the right torque.

Anaerobic sealing issues

According Li and Shipulin (2011) anaerobic adhesive materials belong to the category of rigid materials, and upon cyclic loading a problem of temperature elevation can arise due to hysteresis loss. To Ryakhovskii et al (2015) the disadvantages of anaerobic compositions are low resistance, not exceeding 150ºC for most anaerobic materials. Hence due to this the anaerobic sealants are more used in static gaskets.

For Pantoja et al (2015) the shear strength of anaerobic adhesive joints dramatically increases, and presents a cohesive failure, due to the hydrolysis and condensation rates solution and the condensation solution with pH at 6. This is one reason that anaerobic sealant is more recommended to metal-to-metal contact.

2.6. T-Joints

According to Kreuser and Schmatz (2013) T-joints are the most critical area where surfaces meet each other known as the T-joint, and the typical gaskets found on the T-joints are Forme-In-Place Gasket (FIPG), Single Layer Steel (SLS), Multi-Layer Steel (MLS), and molded rubber types.

This require a special attention on the choice of the sealant to be applied.

When it concerns anaerobic to elastomeric FIP sealants for Kreuser and Schmatz (2013), the flange with anaerobic always has to be assembled first to avoid curing and adhesion problems. If not applying the anaerobic sealing first the sealing will not fill all the necessary regions and it might result in leakage issues on gasket region of the T-joint.

2.7. Design of experiment

According to Hech et al apud Fisher (2016) Design of Experiments (DOE) was developed in 1962 by Ronald A. Fisher, and was first used in agriculture field experiments in a geometry that the results would be independent of environmental biases. For Hech et al (2016) the Design of Experiments (DOE) originated to solve rudimentary experimental problems, but the principles were directly transferable to advanced technologies as mass spectrometry. Nowadays DOE is used on all fields of the industry, and is one of the most important tool for understand the relationship between factors, and optimize process.

To Montgomery (2012) there are two aspects to any experimental problem, which are: the design of the experiment and the statistical analysis of the data, which are closely related due to the method of analysis to depend directly on the design employed.

For Hech et al (2016) for complex experimental designs, and which involves more than one factor, and the order in which factor settings are evaluated is chosen to adhere the following three principles, which are: blocking, randomization and replication. Those principles will be reviewed in the sequence.

- Blocking – For Hech et al (2016) blocking is introduced to account for known experimental biases. To Montgomery (2012) blocking is a design technique used to improve the precision with which comparisons among the factors of interest are made and is often used to reduce or eliminate the variability transmitted from nuisance factors, which may influence the experimental response. As an example, mentioned by Hech et al (2016) in a mass spectrometry, drift can result on a day-to-day basis, and thus may serve as a natural demarcation for block.
- Randomization – According to Montgomery (2012) randomization means that both the allocation of the experimental material to be performed are randomly determined, and statistical methods require that the observations or error to be distributed randomly. For Hech et al (2016) randomization is performed within blocks and protects against unknown or uncontrolled sources of errors. For Montgomery (2012) by properly randomizing the experiment, then also assist in averaging out the effects of extraneous

facts that may be present.

- Replication – For Hech et al (2016) replication can be used to calculate the pure error derived from measurements, the if the measurement error is the primary source of variability as in optimizations studies, then duplicating individual data points, rather than whole studies might be sufficient. For Montgomery (2012) replication means independent repeat run of each factor combination, and it has two important properties, which the first is allowing the experimenter to obtain an estimative of the experimental error, that becomes a basic unit of measurement for determining whether observed differences in the data are statistically different, and second, if the sample mean is used to estimate the true mean response for one of the factor levels in the experiment, then the replication permits the experimenter to obtain a more precise estimate of the parameter. According to Ferreira et al (2016) the replicate results are used to determine the experimental error, which is used to estimate the significance of the factors and their interactions.

Advantages

For Hech et al (2016) the power of Design of Experiment (DOE) is its ability to choose a subset of the full factorial data points, produce model with similar statistical power, and locate the true optimum more efficiently. Also for Hech et al (2016) DOE can be accomplish it by making assumptions about the experimental error based on the replication of a subset of points versus the entire design and using randomization and blocking to reduce biases. Hence it can be assumed that DOE is one of the best techniques of optimization that can be applied on process.

On the DOE review performed by Hech et al (2016) it was concluded that the upfront planning to design an experiment by utilizing well-defined statistical tools ultimately saves time and resources.

Another study performed by Montorsi et al (2015) the Design of Experiment (DOE) approach was used the acquision of the maximum significant information about the effect of the systemic and multi-variated variation of the process variables on final properties of the material. By acquiring this information it was possible to derive mathematical models which could be used in the production, and define the best set of input parameters for the desired output.

According to Alleh et al (2015) statistical designs of experiments has been increasingly employed by engineers and researchers for screening out main effects and optimization issues, due to the ease of data obtainment over a wide range experimental region with a fair degree of accuracy which makes it very attractive. Specially now with automated process and good database information, it becomes easier to perform a DOE and evaluate its results.

2.8. Fractional Factorial Experiment

According to Montgomery (2012) if can be assumed that certain high-order interactions are negligible, then information of the high effects and low-order interactions may be obtained by running only a fraction of the complete factorial experiment. For Montgomery (2012) the fractional factorial designs are among the most widely used type of Design of Experiments for products and process design, process improvement, and industrial or business experimentation. Due to the facility of employing fractional factorial comparing to full factorial, it is preferred in production process, because it saves time and money which is limited in the production shop-floor.

For Mortosi et al apud Montgomery and Colbourn (2015) the degree of factional design resolution mean that the main effects and the two-factors interactions are aliased with three-factor and higher interactions.

According to Saeidi et al (2015) fractional designs enables the simultaneous analysis of several factors and the estimation of both their individual and interaction effects. For Saeidi et al apud Hinkelmann (2015) this statistical method provides wider view and facilitates the understand of the output results in any experimental test design. Hence by knowing the factors, and its interactions significant factors it increases the process knowledge, and facilitates the process setup in order to obtain the optimum level.

Advantages and applications

A fractional factorial design show to have a high contribution for research, and important can be found related to this method.

For Li and Qin (2017) fractional factorial designs with partially replicated runs are desirable, since they not only save experimental cost, but also estimate the experimental error variance. It turns the fractional factorial more interesting and feasible to apply on practice.

Li and Qin (2017) concluded on their study that partially replicated design is able to provide an unbiased estimate of experimental error variance, which also can save runs compared to the fully replicated design. For Sallet et al (2015) fractional design can cover the main effects of the parameters within the whole range of parameters selected. Hence fraction factorial design experiment can be as precise as full factorial, and it depends on the planning and experimenter knowledge.

According to Mukerjee and Tang (2016) the two-level fractional factorial designs under a baseline parametrization arises naturally when each factor has a control or baseline level. Hence fractional factorial permits to understand the influence of each factor and factors interactions which impact on the response.

A study of two-level factorial design was performed by Guyonvarch et al (2015) and was used to identify the significant parameters. Also, on the study of Souza et al (2016) a two-level fractional factorial design was used to screen the variable and present which of them presented a significant effect. For Saeidi et al apud Montgomery (2015) a 2^k fractional factorial, where “k” corresponds to the number of factors where each factor can have 2 levels is widely used for factor screening experiments. Though, fractional factorial design permits to find out the most statistically significant input factors, and work on it as desired.

According to Souza et al (20160 fractional factorial designs are employed when is desired to decrease the number of experimental runs to save time and costs, without loss of evaluation capacity.

A study on apple acceptability was performed by Endrizzi et al (2014) using a two-level fractional factorial design with four factors, being two intrinsic factors, and two extrinsic factors, and no combinations for each consumer were considered the maximum number, and the experimental design chosen was 2^ (4-1) fractional factorial design of resolution IV. This is a very interesting study performed on the nutritional area which studied the effects of the intrinsic and extrinsic factor by using this methodology approach.

Another DOE with fractional factorial design was performed by Saeidi et al (2015) studying the effect of geometrical parameters as diameter, depth, length, area fraction and sliding direction, on microtextures on the average coefficient of friction and the sample lifetime. This study found that the geometrical parameters of micro-textures interact predominantly and in a complex manner.

Also a study using fractional-factorial was performed by Salleh et al (2015) by studying the effect of mechanical alloying parameters as milling time, milling speed, ball-to powder ration and percentage of zinc, and their interactions involving four numerical factors with two replicates, resulting on 16-run of two-level factorial design. It resulted in a reliable fractional factorial experiment design which can be used for binary optimization on Mg-ZN alloy synthesized by mechanical alloy.

3. METHODOLOGY

The nature of this research may be classified as applied. This work was applied in an engine plant process in order to improve the internal quality metrics by reducing defects, and consequently improving process efficiency and reducing the costs of poor quality. According to Appolinário (2006) applied research is referred to business interests, which means that it focused on the development of new process or products guided by the customer needs.

Related to the approach of the problem, the research is quantitative. On this study it will be measured the result of two output variables after setting up the main input parameters at the same time. According to Miguel (2012) the researcher must capture evidences by measuring the variables, though no subjectivism may influence the comprehension from the facts used to generate the knowledge.

Regarding the objective of the research it may be classified as Descriptive Research. After collecting data of the experiment, it will be analyzed the outputs statistic results thru fractional factorial DOE to set up the inputs by using Minitab software. According to Barros and Lehfeld (2007) descriptive research make the study, the analysis, the register and the physical facts without interference from the researcher opinion.

The method used on this research is experiment. This study applies the fractional factorial Design of Experiment to plan and conduct the analysis of the results, and the independent variables are the main inputs chosen by the experiment responsible team. According to Martins et all (2014) the experimental research is the control over the values on which the independent variables will assume, which means that it is up to the experimenter to establish the control of the values that are going to be studied. According to Martins et all (2014) it is a quantitative research method on which the target of the researcher is to demonstrate by using statistical analysis techniques the causal relationship between the dependent variables and independent variables.

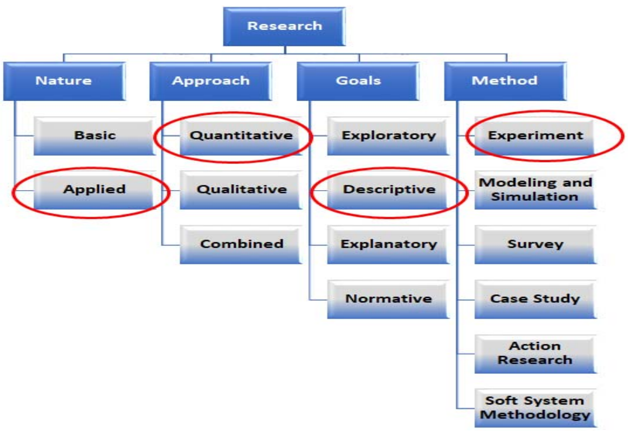

Figure 2. Research classification (Author, 2018).

4. EXPERIMENTAL PLANNING

4.1 Issue description

The main rejection detected on the in-line leak test are due to Anaerobic Seal application failures, the rejections are on the "T-joint" between the cylinder head, anaerobic seal bead, front cap and valve cover gasket.

The schematic drawing illustrated the sealing at the "T-joint" on figure 3.

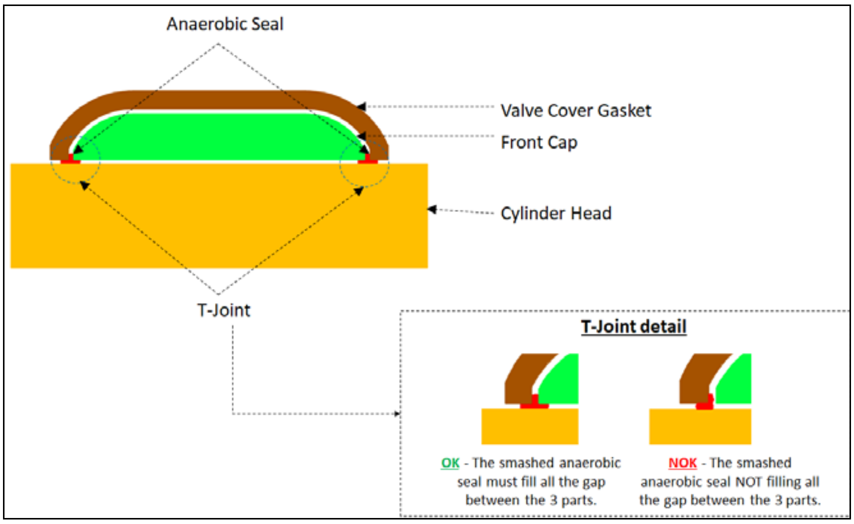

Figure 3. Schematic drawing illustrating the "T-joint" between cylinder head, front cap and valve cover gasket (Author, 2018).

Internaly the rejections on the "T-joint" due to missing or not enough anaerobic seal which corresponds 20% of the total rejections on the leak test.

And with the intention to eliminate at minimum 80% of these rejections a fractional factorial DOE is going to be applied to find the best set of the main input variables in order to optimize the output response. The input varibles and outputs chosen for these fractional factorial DOE is going to be presented on the next section.

4.2 Idetifying input variables and outputs

The anaerobic sealing is applied by an automatic dispensing machine, and in order to raise up the critical input parameters it was done a brainstorming between process specialists, maintenance specialists and supplier.

The result is that the team came up with four critical parameters, which are: temperature from the application hose, temperature panel, robot speed and robot tip distance from the application face. The table 1 illustrate the parameters and the levels to be used on the DOE.

Table 1. Input parameters and ther levels (Author, 2018).

Factor	Levels		
	Minimum (-1)	Maximum (+1)	Remarks
Application hose temperature	25	32	
Pannel temperature	28	32	
Robot tip distance	1,5	2	
Robot speed	70%	100%	Potentiometer adjustment

These parameters were used to set the machine as one factor at a time, but the interactions between all these parameters are unknown by the team.

The outputs to measure are the bead diameter right after application (Y1) and the leak rate (Y2) on leak test.

The desired response for bead diameter (Y1) is maximum diameter, since it will fill the gaps on the joint and prevent leakage.

The desired response for leak rate (Y2) on leak test is minimum leak rate with air.

5. RESULTS AND DISCUSSIONS

In this chapter it will be shown the DOE planning for data collections and experimental analysis.

5.1 DOE Execution

Before running the experiments it was planned the 2^{4-1} level factorial with twoo replications for the four critical input parameters: panel temperature, application hose temperature, robot speed and robot tip distance. It was also planned the runs in a randon sequence by using minitab software.

Before start the experiment it was performed a trial run, in order to evaluate the levels set-ups of the four critical inputs simultaneously, and the measurement of the outputs as anaerobic sealant bead diameter (mm) and leakage (ccm).

On the next step the experiment was performed in the sequence according to the minitab randomization, and collected data for sealant bead diameter (mm), and leakage (ccm), as shown on table 2.

Table 2. DOE experiment plan and data collection (Author, 2018).

StdOrder	RunOrder	Application hose temperature	Pannel temperature	Robot tip distance	Robot speed	(Y1) Seal bead diameter (mm)	(Y2) Leakage (ccm)
9	1	-1	-1	-1	-1	4	0.283401
6	2	1	-1	1	-1	3	0.278315
12	3	1	1	-1	-1	5.1	0.203292
3	4	-1	1	-1	1	3.5	0.261784
5	5	-1	-1	1	1	3.4	0.204563
11	6	-1	1	-1	1	4.3	0.200749
8	7	1	1	1	1	1.8	0.235082
15	8	-1	1	1	-1	3	0.233809
16	9	1	1	1	1	3.2	0.231267
14	10	1	-1	1	-1	2.9	0.227452
10	11	1	-1	-1	1	3.6	0.22618
13	12	-1	-1	1	1	1.8	0.23381
7	13	-1	1	1	-1	2.7	0.191848
2	14	1	-1	-1	1	3.7	0.19477
4	15	1	1	-1	-1	5	0.441076
1	16	-1	-1	-1	-1	4.8	0.186761

5.2 Factor effects

It was performed a calculation using minitab for the effects of each factor and the interactions with each output (seal bead variation and air leakage).

The effect for each factor and main interactions for bead seal width are shown on table 3.

Table 3. Effect analysis for each factor and main interactions (Author, 2018).

Bead seal width variation		
Code	Term	Effect
A	Application hose temperature	0.1
B	Pannel temperature	0.175
C	Robot tip distance	-1.525
D	Robot speed	-0.65
A*B	Application hose temperature*Pannel temperature	0.3
A*C	Application hose temperature*Robot tip distance	-0.1
A*D	Robot tip distance*Robot speed	-0.275

The factors: Application hose temperature, pannel temperature, robot tip distance and robot speed are coded as "A", "B", "C" and "D".

The main effect for the output bead seal width is "robot tip distance". On the individual plot at figure 4 it is possible to understand the effect of each factor on the response.

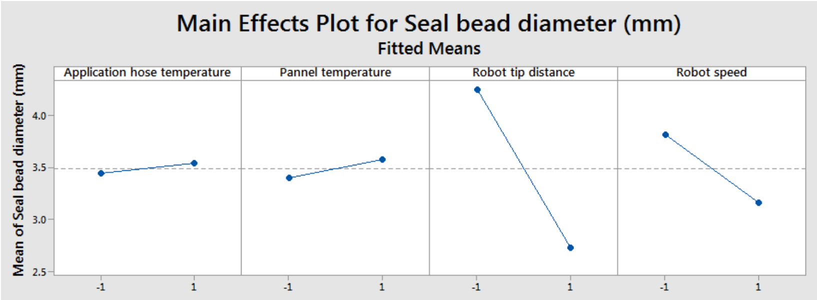

Figure 4: Factors effect plot for seal bead diameter (Author, 2018).

The effect for each factor and main interactions leak test air leakage are shown on table 4.

Table 4. Effect analysis for each factor and main interactions (Author, 2018).

Air leakage		
Code	Term	Effect
A	Application hose temperature	0.0301
B	Pannel temperature	0.0205
C	Robot tip distance	-0.0202
D	Robot speed	-0.0322
A*B	Application hose temperature*Pannel temperature	0.0255
A*C	Application hose temperature*Robot tip distance	-0.0031
A*D	Application hose temperature*Robot speed	-0.0335

The factors: Application hose temperature, pannel temperature, robot tip distance and robot speed are coded as “A”, “B”, “C” and “D” respectively.

The main effects for the output air leakage are “aplication hose temperature” and “robot speed”. On the individual plot at figure 5 it is possible to understand the effect of each factor on the response.

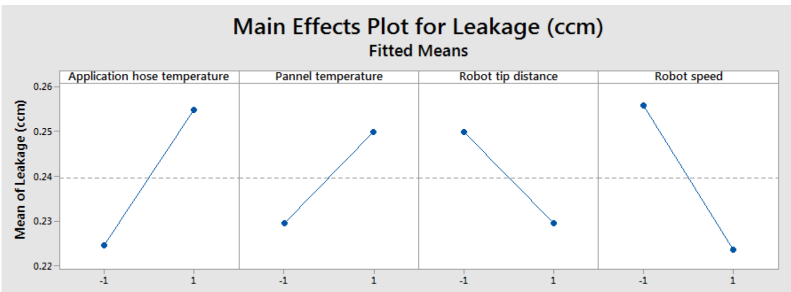

Figure 5. Factors effect plot (Author, 2018).

5.3 Test of significance or Hypothesis test

It was performed a significance test for each effect and the main interactions for each output (seal bead width and air leakage).

The significance test for each factor and main interactions for bead seal diameter are shown on table 5.

Table 5. Test of significance for factors of seal bead diameter (Author, 2018).

Bead seal width		
Code	**Term**	**T-Value**
A	Application hose temperature	0.33
B	Pannel temperature	0.58
C	Robot tip distance	-5.01
D	Robot speed	-2.14
A*B	Application hose temperature*Pannel temperature	0.99
A*C	Application hose temperature*Robot tip distance	-0.33
A*D	Application hose temperature*Robot speed	-0.9

Considering 8 degrees of freedom for the whole experiment with a significance level α = 0.05 (confidence level of 95%), results a critical values of "t"equal to 2.306, and the only significant factor is "C" (robot tip distance), which t-value is 5.01 and bigger than 2.306. Then it can be concluded that the robot top distance has a significant effect on the seal bead width variation.

The mathematical model for seal bead width output is: 3.488 + 0.050 A + 0.088 B - 0.762 C - 0.325 D + 0.150 A*B - 0.050 A*C - 0.138A*D.

The significance test for each factor and main interactions air leakage are shown on table 6.

Table 6. Test of significance for factors of air leakage (Author, 2018).

Air leakage		
Code	**Term**	**T-Value**
A	Application hose temperature	0.87
B	Pannel temperature	0.59
C	Robot tip distance	-0.59
D	Robot speed	-0.94
A*B	Application hose temperature*Pannel temperature	0.74
A*C	Application hose temperature*Robot tip distance	-0.09
A*D	Application hose temperature*Robot speed	-0.97

Considering 8 degrees of freedom for the whole experiment with a significance level α = 0.05 (confidence level of 95%), results a critical values of "t" equal to 2.306, and no factor or interaction was significant for air leakage. Then it can be concluded that no factor and the interactions of the factor has no significant effect on air leakage.

The mathematical model for seal bead width output is: 0.2396 + 0.0150 *Application hose temperature + 0.0102 * Pannel temperature - 0.0101 * Robot tip distance - 0.0161 * Robot speed + 0.0128 * Application hose temperature * Pannel temperature - 0.0015 Application hose temperature * Robot tip distance - 0.0167 * Application hose temperature * Robot speed.

5.4 Interaction for effects

In order to understand the best set-up of the inputs for maximizing the seal bead diameter output and minimizing air leakage it was plotted on minitab the interaction graphic for each output according to figure 6 and figure 7.

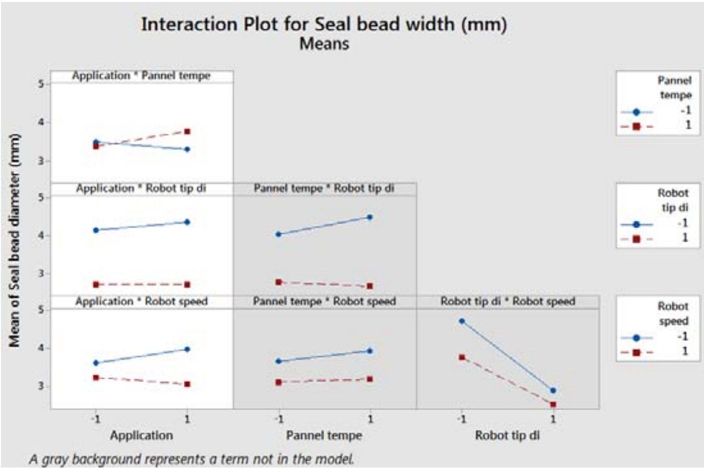

Figure 6. Interaction plot for the seal bead width input parameters (Author, 2018).

By analyzing the interaction plot for seal bead width output, it can be concluded that the input parameters should be set according: Application hose temperature: +1 (32ºC); Pannel temperature: +1 (32ºC); Robot tip distance: -1 (1,5 mm); Robot speed: -1 (70%).

The set-up "robot speed" with 70% would impact on production, making the operation a bottle neck, but as seen on the section 4.3 this factor is not considered significant, then it was decided to keep it at 100% of speed.

In order to understand the best set-up of the inputs for minimizing air it was plotted on minitab the interaction graphic for each output according to figure 6.

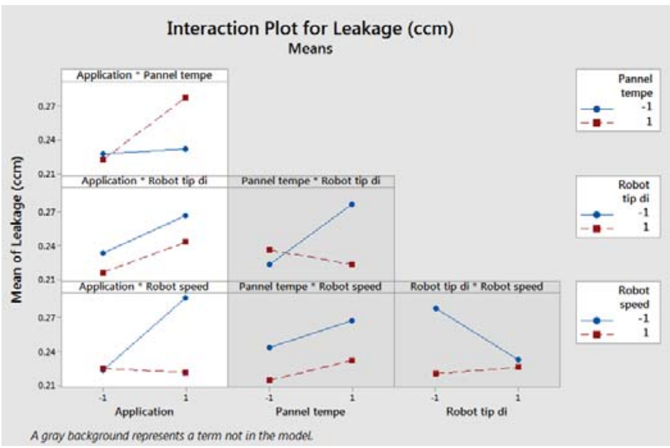

Figure 7. Interaction plot for the air leakage input parameters (Author, 2018).

By analyzing the interaction plot for air leakage output, it can be concluded that the input parameters should be set according: Application hose temperature: -1 (25ºC); Pannel temperature: -1 (28ºC); Robot tip distance: -1 (1,5 mm); Robot speed: 1 (100%).

5.5 Confirmation of the proposal input setups

In order to set-up the best configuration in order to maximize the seal bead diameter and minimizing air leakage, it was performed an optimization analyzis by using the response optimizer from minitab for the twoo optputs simultaneously.

As shown on figure 8, the best set-up of the input parameters are:

- Application hose temperature: -1 (25ºC);
- Pannel temperature: -1 (28ºC);
- Robot tip distance: -1 (1,5 mm);
- Robot speed: 1 (100%).

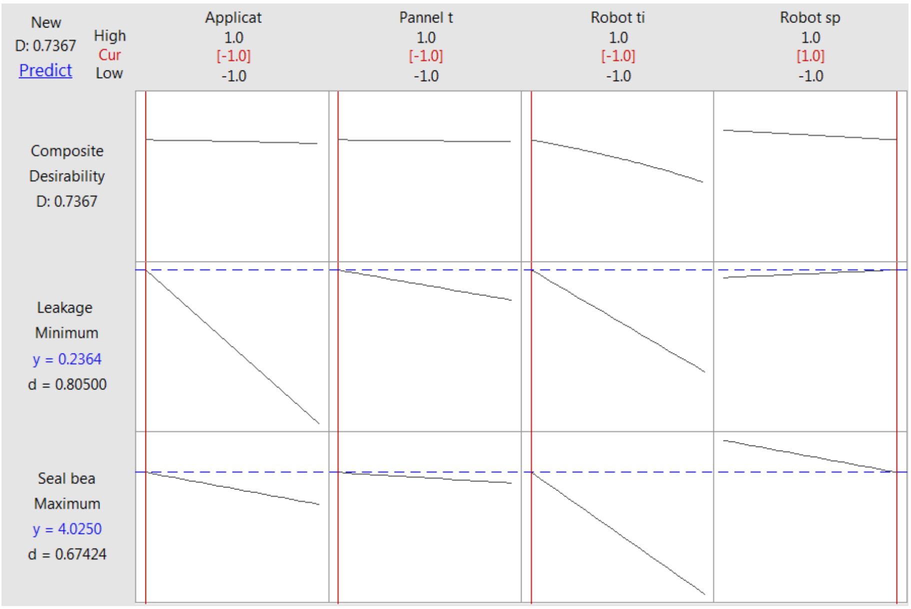

Figure 8. Interaction plot for the air leakage input parameters (Author, 2018).

The setup shown on figure 8 will result in a air leakage of 0.2364 ccm and a seal bead width of 4.0250.

6. CONCLUSIONS

The fractional factorial DOE was employed in order to set-up process inputs parameter to apply anaerobic seal and avoid leakage on “T-Joint” for the intersection of the cylinder head, anaerobic seal bead, front cap and valve cover gasket, and consequently improved line capacity by avoiding engines being rejected on the leak test.

The noise factors as humidity and environmental temperature which affects the results were not considered, then the DOE does not consider long term variation. The inputs effect for the leak rate (Y1) on leak test might not be significant due to it, but the seal bead diameter (Y2) showed to have significant effect specially for robot tip distance. The seal bead diameter (Y2) is the most robust output to work on for this application because the maximum diameter that the limits that each input factor can reach will allow the anaerobic seal to fill all gap area and eliminate the leak on the "T-joint" region.

The result of the best set of the input variables of the anerobic seal application provided by the fractional factorial DOE exceed the minimum of 80% improvement achievement zero rejections on the leak test at the "T-joint" region.

The inputs setup which lead this improvement are: 1-) appplication hose temperature at 25ºC; 2-) pannel temperature at 28ºC; 3-) robot tip distance at 1,5mm; 4-) robot speed at 100%. After the setup of these parameters it was followed by six month the result on production leak test and no more rejection was detected on this region.

REFERENCES

Appolinário, F. Metodologia da ciência – filosofia e prática da pesquisa. São Paulo: Editora Pioneira Thomson Learning, 2006.

Barros, Aidil J. da S.; Lehfeld, Neide Aparecida de S. Fundamentos de metodologia científica. 3. ed. São Paulo: Pearson Prentice Hall, 2007.

Barros Neto, Benício de; Scarminio, Ieda Spacino; Bruns, Roy Edward. Como fazer experimentos: pesquisa e desenvolvimento na ciência e na indústria. 3. Ed. Campinas, SP: Unicamp, 2007.

Bautista, J., Alfaro, R., Batalla, C. Modeling and solving the mixed-model sequencing problem to improve productivity. International Journal of Production Economics, 161, pp. 83-95, 2015.

Endrizzi, I., Torri, L., Corollaro, M.L., Demattè, M.L., Aprea, E., Charles, M., Biasioli, F., Gasperi, F. A conjoint study on apple acceptability: Sensory characteristics and nutritional information. Food Quality and Preference, 40 (PA), pp. 39-48, 2015.

Ferreira, S.L.C., Caires, A.O., Borges, T.D.S., Lima, A.M.D.S., Silva, L.O.B., dos Santos, W.N.L. Robustness evaluation in analytical methods optimized using experimental designs. Microchemical Journal, 131, pp. 163-169, 2017.

Guyonvarch, E., Ramin, E., Kulahci, M., Plósz, B.G. ICFD: Interpreted Computational Fluid Dynamics - Degeneration of CFD to one-dimensional advection-dispersion models using statistical experimental design - The secondary clarifier. Water Research, 83, pp. 396-

411, 2015.

Halim, N.H.A., Jaffar, A., Yusof, N., Jaafar, R., Adnan, A.N., Salleh, N.A.M., Azira, N.N. Standardized work in TPS production line. Jurnal Teknologi, 76 (6), pp. 73-78, 2015.

Halim, N.H.A., Yusuf, N., Jaafar, R., Jaffar, A., Kaseh, N.A., Azira, N.N. Effective Material Handling System for JIT Automotive Production Line. Procedia Manufacturing, 2, pp. 251-257, 2015.

Hecht, E.S., Oberg, A.L., Muddiman, D.C.; Optimizing Mass Spectrometry Analyses: A Tailored Review on the Utility of Design of Experiments. Journal of the American Society for Mass Spectrometry, 27 (5), pp. 767-785, 2016.

Kharat, A.H., Gadewar, S.P., Gawande, S.H. Numerical and experimental investigation of structural gasketing approach for gearbox flange. International Review of Mechanical Engineering, 11 (7), pp. 520-529, 2017.

Kreuzer, R., Schmatz, T. Worldwide Sealing Guidelines for Liquid Sealants. Henkel AG & Co. KGaA, 2013.

Lalami, I., Frein, Y., Gayon, J.-P.; Production planning in automotive powertrain plants: a case study. International Journal of Production Research, 55 (18), pp. 5378-5393, 2017.

Li, R.I., Shipulin, M.A. Evaluative quality parameters in nondestructive control of adhesive metallic bonds in machine units. Polymer Science - Series D, 5 (1), pp. 15-19, 2012.

Li, H., Qin, H. Construction on two-level factorials with flexible partially replicated runs via quarter foldover. Journal of Statistical Planning and Inference, 188, pp. 55-66, 2017.

Martins, Roberto Antonio; Mello, Carlos Henrique Pereira; Turrioni, João Batista. Guia para elaboração de monografia e TCC em engenharia de produção. São Paulo: Editora Atlas, 2014.

Miguel, PAC. (org.). Metodologia de pesquisa em engenharia de produção e gestão de operações. 2. Ed. Rio de Janeiro: Elsevier/ABEPRO, 2012.

Montgomery, Douglas C. Montgomery. Design and Analysis of Experiments. Eighth ed., John Willey & Sons. 2012.

Montorsi, M., Mugoni, C., Passalacqua, A., Annovi, A., Marani, F., Fossa, L., Capitani, R., Manfredini, T.; Improvement of color quality and reduction of defects in the ink jet-printing technology for ceramic tiles production: A Design of Experiments study. Ceramics International, 42 (1), pp. 1459-1469, 2015.

Mukerjee, R., Tang, B. Optimal two-level regular designs under baseline parametrization via cosets and minimum moment aberration. Statistica Sinica, 26 (3), pp. 1001-1019, 2016.

Pandian, A., Ali, A.; Investigation of maintenance assumptions for an automotive production line using simulation modeling. IEOM 2015 - 5th International Conference on Industrial

Engineering and Operations Management, Proceeding, art. no. 7093773, 2015.

Pantoja, M., Abenojar, J., Martínez, M.A., Velasco, F. Silane pretreatment of electrogalvanized steels: Effect on adhesive properties. International Journal of Adhesion and Adhesives, 65, pp. 54-62, 2016.

Ryakhovskii, O.A., Malysheva, G.V., Vorob'ev, A.N. Method for reaching air-tightness of the joint between the casing of an impeller pump and its cover. Russian Metallurgy (Metally), 2016 (13), pp. 1312-1316, 2016.

Saurabh Jha, P., Khan, M.S. An experimental study on the automotive production line using assembly line balancing techniques. International Journal of Mechanical Engineering and Technology, 8 (3), pp. 22-33, 2017.

Song, J., Kim, S., Liu, Z., Quang, N.N., Bien, F. A Real Time Nondestructive Crack Detection System for the Automotive Stamping Process. IEEE Transactions on Instrumentation and Measurement, 65 (11), art. no. 7506091, pp. 2434-2441, 2016.

Segura Velandia, D.M., Kaur, N., Whittow, W.G., Conway, P.P., West, A.A.; Towards industrial internet of things: Crankshaft monitoring, traceability and tracking using RFID. Robotics and Computer-Integrated Manufacturing, 41, pp. 66-77, 2016.

Saurabh Jha, P., Khan, M.S. Standardized work in TPS production line. Jurnal Teknologi, 76 (6), pp. 73-78, 2015.

Sawa, T., Sasaki, R. An analysis of pipe flange connections using epoxy adhesives/anaerobic sealant instead of gaskets. Journal of Pressure Vessel Technology, Transactions of the ASME, 117 (4), pp. 298-304, 1995.

Schuhmacher, N., Göttler, A.; Efficient gasket concepts for commercial vehicles. Sealing Technology, (3), pp. 12-13, 2007.

Saeidi, F., Meylan, B., Hoffmann, P., Wasmer, K. Effect of surface texturing on cast iron reciprocating against steel under starved lubrication conditions: A parametric study. Wear, 348-349, pp. 17-26, 2016.

Salleh, E.M., Zuhailawati, H., Ramakrishnan, S., Gepreel, M.A.-H.; A statistical prediction of density and hardness of biodegradable mechanically alloyed Mg-Zn alloy using fractional factorial design. Journal of Alloys and Compounds, 644, pp. 476-484, 2015.

Souza, V.S., Teixeira, L.S.G., Bezerra, M.A.; Application of multivariate designs in the development of a method for vanadium determination in natural waters by HR-CS GF AAS after cloud-point extraction. Microchemical Journal, 129, pp. 318-324, 2016.

Wu, Y. Design Factor Analysis Based on Fractional Factorial Experiment. Mechanisms and Machine Science, 55, pp. 495-506, 2018.

Yang, J., Mandal, A., Majumdar, D.; Optimal designs for 2k factorial experiments with binary response. Statistica Sinica, 26 (1), pp. 385-411, 2016.

Yan, L., Liu, F., Feng, Z., Wei, Z.. Study of an automatic logistics system for the engine production line. Proceedings of the World Congress on Intelligent Control and Automation (WCICA), 2015-March (March), art. no. 7053603, pp. 5217-5221, 2015.

Zhou, Z., Dou, Y., Sun, J., Jiang, J., Tan, Y. Sustainable production line evaluation based on evidential reasoning. Sustainability (Switzerland), 9 (10), art. no. 1811, 2017.