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Statistical Analysis of Silicone Oil Flow through drilled plates used in RC cars

REPORT

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Statistical Analysis of Silicone Oil Flow through drilled plates used in RC cars

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F = variance coefficient
h = signal to noise ratio
phd = perimeter holes diameter
chd = centre hole diameter
hl = hole length
adc = average damping coefficient
adct = average damping coefficient on traction mode
adcc = average damping coefficient on compression mode

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Abstract: the present work studies how to determine the best combined dimensions of control variables to achieve an optimal mass flowrate in order the better damping performance on radio-controlled vehicles. According to this, we are going to design a DOE based on Taguchi´s (10) to measure the influence of fluid viscosity (μ), perimeter holes diameter (PHD), centre hole diameter (CHD) and hole length (HL) of different drilled plates used as a critical part of a RC vehicle damper. This DOE design will be L16 with three control variables already described and a fixed value (μ, WAGNERSIL S200). On the other hand, drilled plates will be 3d printed and self-designed by CAD, using ARTILLERY SIDEWINDER X1 "fdm" printing system.

Keywords: RC vehicles, damper, Taguchi, ANOVA, Minitab, Silicone Oil, drilled plate.

Justification: Through the analysis of the performance and optimization of the shock absorbers in radio control vehicles, driven by the study of behavior for the control variables of the present work, more mechanically efficient elements are achieved that can be precursors even in vehicles with a higher capacity of cargo, whether they are utilities, trucks or industrial machinery.

Likewise, the present work has served as investigation of new theories in the field of statistics such as the Taguchi method for the design of experiments and the verification by the ANOVA method of the results by univariate analysis.

From a scientific point of view, this project is based on empirical tests through the construction and commissioning of a model that simulates the behavior of our damping system for RC vehicles, which highlights the importance of the practices developed During the degree, in which we have learned to make measurements correctly, calculate errors and process the obtained data.

Origin of work:

I decided to do this final project because when i was young i got first fuel Radio Control car from 11 years old.
From 17 years old until 27 years old i dedicated at high competition of Radio Control cars doing Catalonia, Spanish and European championships, got 3 Catalonia championships in 2001 / 2002 / 2003 consecutive, after i tryied Spanish championship during some years, the best result was 8 position in 2006, and one European championship get 9 position in 2007, for this reason i was my final project about this.

Methods that have been left out of work:

We would have loved to be able to make a video to understand the effects on the work I have done, we would have loved to go to a circuit but due to Covid-19 circumstances we are confined at home.
Unfortunately in February we had to modify the TFG and for reasons of confinement we have not been able to show any video to show.

1. Historical introduction

There is no exact date for the start of Auto modeling, however, shortly after the Second World War, cars appear whose movement resembles a version of the circular flight aircraft, but on land. Radio-controlled car modeling was born taking advantage of digital proportional control radios and methanol engines, developed in model aircraft. The first car that took shape as we know it today was the asphalt in 1/8 scale, rear-wheel drive, without suspension, with 3.5 cc engine, methanol fuel, and two-channel radio, although there were previous prototypes with engines 6 cc, interiors to the car, which required refrigeration. Aeromodelling engines had to specialize for cars: good response to all regimes (a car accelerates and brakes, unlike an airplane), improved cooling, and noise control. This type of vehicle has become increasingly popular with the advancement of technology and its massification.

There are from toys to professional radio-controlled cars which can be classified from different characteristics such as:

- Type of engine; electric or combustion.
- Scale; Vehicle size with respect to a real one and they are the following: ¼, 1/6, 1/8, 1/10, 1/16, 12/32 and 123/3. The most popular are 1: 8 and 1:10.
- Traction; which is the number of driving wheels. There are only two configurations:
- Normal traction. When the driving wheels are two, the rear or the front, and is also designated by the English acronym 2WD (2 Wheels Driving).
- Integral traction. When all four wheels of the self -model they are motor, and it is also designated by the English acronym 4WD (4 Wheels Driving).
- Category; It is according to whether they are designed to run on asphalt or dirt, and if they can withstand jumps without being damaged. The denominations used are Off road, On road, Monster, Drifting, Rockcrawling, Short Course, Bashers and Touring.

The main categories, which are recognized by all international federations are:

- Track; On -Road. In this category there are scales 1/4, 1/5, 1/8 and 1/10. On scales 1/4 and 1/5 (Large Scale) there is only 2WD traction; on the 1/8 scale the traction is 4WD; while on the 1/10 scale the traction can be 2WD or 4WD.
- SUV; Off-road. In this category is the 1/8 scale with 4WD traction, the 1/10 scale with 2WD and 4WD.
- Tourism
- Rally; Only officially recognized in countries such as Italy and Spain. Officially, there are only 1/8 and 1/10 scales.

Several commercially viable RC cars were available in mid-1966, produced by the Italian company El-Gi de Reggio Emilia. His first model, a Ferrari 250LM 01:12 was available in the United Kingdom in December 1966, through Motor Books and

Accessories importers, St. Martins, London, and early 1967 through the Atkinson model store in Swansea. This model was followed by El-Gi 1:10 Ferrari P4, which is shown for the first time at the Milan Toy Fair in early 1968.

Figure 1. Ferrari 250LM 01:12 model

In the mid-1960s a British company, Mardave, based in Leicester, began producing commercially viable RC cars. His first cars were nitro-or gas cars sold in the area in the early 1970s. In the early 1970s several commercial products were created by small businesses in the US. Most of them started as slot car companies and with the decline in popularity of this genre moved in the field of R / C. Among these were Associated Electrics, Thorp, Dynamic, Taurus, Delta, and Scorpio. These first kits were 1/8 nitro- powered scale Aluminium flat pan cars with motor 0.21 or less. The bodies of these cars were made of polycarbonate. The most popular engine was the K and B Veco McCoy. The main regulatory body for the racing of these cars is Racers Auto.

In 1973-1974, Jerobee, a Washington-based company, created its 1/12 nitro car with a 0.049 Cox engine. Several companies in the market created parts for this car in particular Lexan clear organs , heat sinks and larger fuel tanks. This scale became 1/12 of electric racing scale when Associated Electrics created the RC12E in 1976-77 - Jerobee became Jomac and created his own electric kit called the Lightning 2000 that won the "roar" 1981 National Championship and 82 of 6 modification cells and 82 6-cell production classes.

The 2000 Lightning was designed by Don McKay and Jon Congdon. In the late 1970s, interests in 1/12 scale electric racing began to grow as eighth scale IC racers, the only category that rivals over time, they need to run throughout the winter as an alternative to impracticable IC cars 1/12 cars began to race, therefore, a national winter series has been developed. As a result, the series grew in popularity as a large number of scratch cars.

In 1976, the Japanese firm Tamiya, which was recognized for its plastic model kits decorated in detail, launched a mechanically simple road series; The car models that are sold as suitable for Tamiya radio control soon began. More cars were produced on the subject of remote control, and they launched all-terrain buggies that offer real suspension systems. It was this progression to the off-road class that caused much of the popularity of the fans, since it meant remote control cars that were no longer limited to asphalt and smooth surfaces, but could be driven virtually anywhere. The first true line of Tamiya off-road vehicles was the Scorcher Arena and the Rough Rider, both released in 1979, and both based on realistic buggy designs.

Figure 2. Scorcher Arena model

Tamiya continued to produce vehicles with work suspensions, more powerful engines, rubber-textured off- road tires and various stylized buggy bodies. They also produced trucks, such as the Hilux Toyota pickup, which featured 3 gearboxes and leaf spring suspension systems. All these models

were realistic, durable, simple to assemble, susceptible to being modified and easy to repair. They were so popular that they could be credited as the heyday in radio control model cars in the first half of 1980, and served as the basis for today's radio control car market.

The most popular Tamiya models were Clodbuster grasshopper monster trucks and Hornet buggies, as well as Blackfoot and the first models. Recognizing its continued popularity, several of the first kits have even been re-released by Tamiya during the 2005-2007 period, with some modifications.

A British company, Schumacher Racing, was the first to develop an adjustable ball differential in 1980, which allowed almost infinite tuning for various track conditions. At the moment, most road cars had a solid axle, while off-road cars generally had a gear type

differential. Team Associated did the same with the introduction of the RC100 gas 1/8 scale car on the road, RC12 1/12 scale electric cars on the road and RC10 1/10 scale all-terrain electric race car in 1984.

Team Losi continued with the Introduction of the JRX2 in 1988.

In Spain, the beginnings are from the first permanent asphalt circuit in Igualada (1978), after which several Catalan, Madrid and Valencian enthusiastic pilots and organizers created AECAR (Spanish Association of Radio Control Cars) in 1979, with Francisco Arnaldo as first president, association that later published the famous Red Book, first where the translated European regulations appeared. In 1976, the love of cars and in particular modeling, prompted a group of Igualadinos to form the first automobile club in Spain and one of the pioneers in Europe. The first tests were carried out in the parking lot of a well-known textile factory in Igualada and, in 1977, the construction of an asphalt track specially designed for these cars began on a site near the General Vives Igualada airfield-Odena.

In 1978 the ICAR Club becomes part of the European Federation "EFRA", newly constituted, and enters what could be called "The circus of Formula 1 on scale" The first important test takes place that same year with the first Championship of Catalonia. The event has a great impact giving rise to the 1979 Efra Grand Prize award, this being the first international test conducted in Spain.

Figure 3. Efra Grand Prix, 1979

The Igualada circuit was also followed by the permanent asphalt of Alcira (Valencia), home of the unforgettable Carmen Picó trophy in 1980, Miralbueno (Zaragoza) and Paesa (Madrid), but the most common circuits have been those of all terrain, construction Much easier, faster and cheaper.

National manufacturers have been present. There were 1/8 track cars from Tecnic, Zamicar, Bycmo and Modelhob; The latter made attempts with a 3.5 cc car engine. Bycmo also made 1/8 track and off-road cars, winning several times the Spanish TT championship, as well as 1/7 trucks and 1/4 and 1/5 cars (petrol engine), and since 1991 1/7 cars (on this scale, until 1998, it has produced more than 30,000 units);

In 2002, it sent cars by fascicles to all the kiosks in Spain and also exported this idea. Crojet develops since 1995 a complete line in 1/4 and 1/5; subsequently Contrast. In 1996, the ICAR club undertook an ambitious project that culminated in the construction of a new circuit, which was named ICAR-II. This new circuit occupied an area of 6500m2., It had a 480mt track. Long and 5m wide and was considered the best in Europe.

Figure 4. ICAR II circuit, 1996

Currently, in 2011, the ICAR club undertakes a new project, in this case maintaining the original RC track, and building what has been called ICAR INDOOR, in facilities with 510m2. In this new stage, the club is committed to introducing the Slot within its disciplines, thus expanding the existing offer and making available to everyone, in addition to the already known and usual route for RC racing:

- Speed track 1 / 24 with 6 lanes and a route of 64 mt.
- 1/32 speed track with 6 lanes and a 47 mt route.
- RC track for electric cars of 1/12, 1/18 and Mini Z scale Each section is individually equipped with time and box control and monitoring

Figure 5. ICAR Indoor, 2011

2. Types of dampers

The operation of the shock absorber is based on the circulation of oil between the internal devices through a set of valves that generate resistance to the passage thereof between the shock absorber chambers. In this way the oscillations of the suspension are controlled (1).

- Expansion (the damper is open): For the damper is open, the piston needs to rise and this can only be achieved if the oil is above the piston flows through this. To control the passage of oil, there are the holes located in the neck of the piston and the grooves that are made (coded) in the seat of the expansion valve. In addition to the holes and grooves, there is also the expansion spring that keeps the valve under controlled pressure. The action of these three elements provides the damping forces that are known as hydraulic resistors.

- Compression (the damper is closed): which the damper is closed, the piston needs to lower and this is only achieved if the oil is at the bottom of the piston flows to through this. To control the passage of oil, there are the holes located in the piston body and the grooves that are made (coded) in the compression head where the replacement valve is located. In addition to the holes and the slots, it is also the compression spring located in the head of compression that maintains the controlled valve. As in the expansion, the work of these elements, generates the damping forces that are known as hydraulic resistors.

Now that we know how is its definition, composition, its principle of operation and the rules that govern it to be commercialized, we can move on to the central theme of this work, which are the types of shock absorbers.

- Conventional hydraulic shock absorbers: Those in which the damping force, to control the movements of the suspended and non-suspended masses, is obtained by forcing the passage of a fluid through calibrated steps of differentiated opening, in order to obtain the flexibility needed for vehicle control in different states. They are the most usual and cheap but their duration is limited and they show loss of efficiency with excessive work, due to the increase in temperature. They are not usually used in sports driving or competition. The ambient temperature and the heat absorbed by the oil in the operation of the hydraulic dampers, influence the viscosity of the liquid, causing it to pass with more or less difficulty through the valves that separate the chambers, resulting in a more or less damped suspension. For this reason, in winter, in the first moments of operation, a harder suspension is observed, since the oil due to the cold has become denser; In summer or when the vehicle is traveling on uneven terrain, the oil becomes more fluid and a softer suspension is noticeable. One of the advantages of this type of shock absorber is that it does not require any maintenance, so it can save us several inconveniences.

Figure 6. Conventional spring shock absorber

- Pressurized hydraulic shock absorber: An advance in the evolution of the shock absorbers consists in pressurizing the interior of the shock absorbers, this brings with it a series of advantages. In the pressurized, a low pressure gas chamber (4 bar) is added and the compression damping force is still provided by the oil as it passes through the piston valves. In this way the extension force made by the shock absorber in its nominal position is low. This allows this solution to be used in McPherson suspensions where higher buffer diameters are required.

  Its advantages over non-pressurized are the following:

  - Response of the most sensitive valve for small amplitudes.
  - Best comfort.
  - Better damping properties in extreme conditions (large potholes).
  - Reduction of hydraulic noise.
  - They are still working, even if they lose gas.

- With respect to mono-tube dampers, pressurized double-tube dampers have the advantage of having a shorter length and friction for the same operating conditions.

• Dampers of gas: These work on the same basic principle that hydraulic, but contain in one of its ends to high pressure nitrogen (approximately 25 bars). A floating piston separates this gas from the oil preventing it from mixing. When the oil to the moving rod, compresses the gas, is undergoes a volume change that allows to give instant feedback and one operation silent. The gas shocks well as cushion also make somewhat of spring elastic, that is why these types of shock absorbers return to their position when they stop acting on them. In turn, within this category are the adjustable and non-adjustable.

Figure 7. Gas damper

- Dampers of gas not adjustable: usually be dampers monotube or twin tube, very shock resistant, high durability and high resistance to loss of effectiveness by temperature working. Although the price is higher, it is compensated for its durability and reliability. It is a very high quality type of shock absorber. Its use is recommended for high performance vehicles.

Figure 8. Not adjustable gas damper

- Dampers of gas adjustable: are monkey tube, with or without botella exterior, with the possibility of variation. It is a type of high- tech shock absorber, with a high price but proportional to its effectiveness, so it is the most used in sports driving, in competition and high performance vehicles.

Figure 9. Adjustable gas damper

- Hydraulics with valves

The pistons are replaced by valves, whose function is to pass the oil when there is pressure. For this reason, these shock absorbers are much more efficient than the previous ones because they provide greater smoothness in driving.

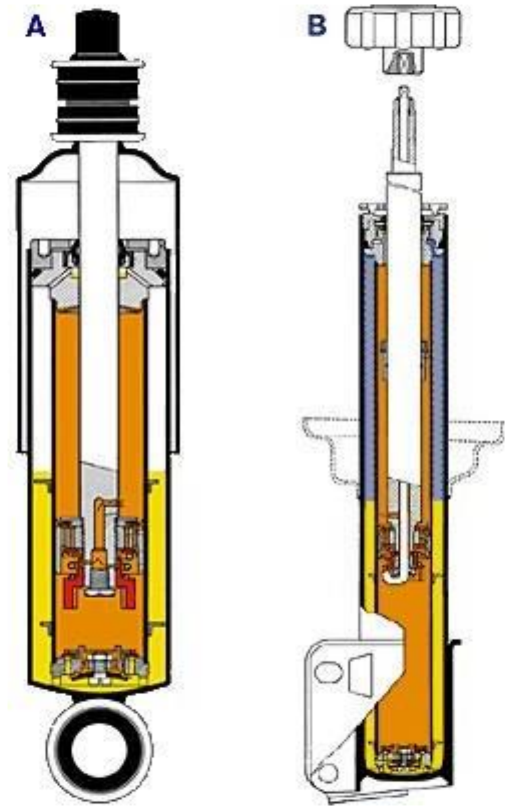


Figure 10. Hydraulic shock absorber with valves

- Damper adjustable in hardness

This type of shock absorber allows to regulate the hardness of the damping to suit the user making modifications in the oil flow. This is achieved thanks to a thread that widens or reduces the diameter of the hole through which the oil passes. Its great advantage is the flexibility that they provide to the user, who can configure them to their liking for the type of terrain on which they will be used at that time. This is achieved by adjusting the pitch control screw that has three soft, medium and hard positions. This can give the user the benefits that he wants in his vehicle, for example, when driving through the city it would be placed in soft or medium and for the road it would be hard, thus avoiding a risk of overturning.

This is a mechanical type system, but currently there are suspensions that can make the shock absorber adaptive to the speed, since they are low speeds in soft for better maneuverability and high rigidity.

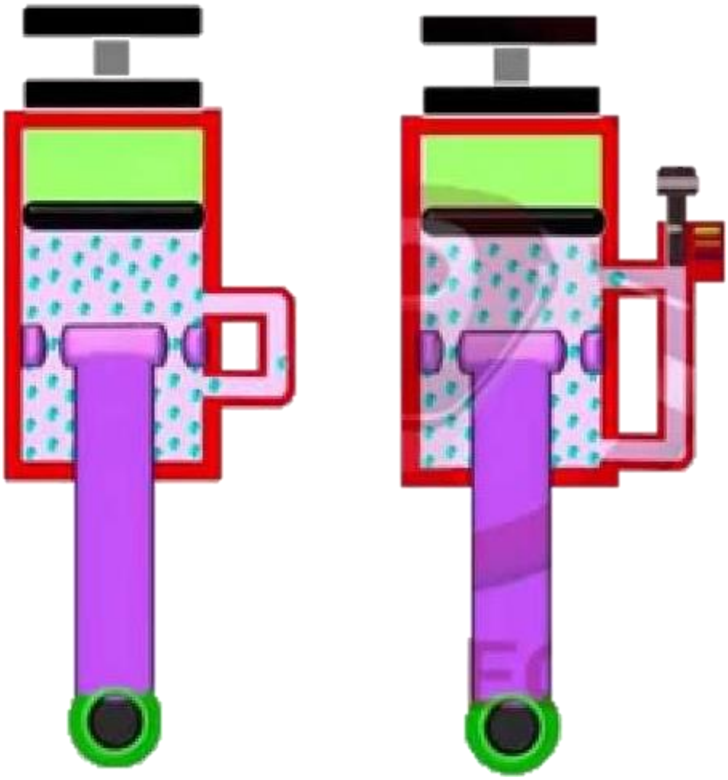


Figure 11. Strength adjustable damper

- Damper adjustable in suspension

In this case, what we regulate is the height or distance that we want to exist between the body of the vehicle with respect to the floor. That is, we raise or lower the damping. This is applicable to the fact that if we travel on the road we can lower the suspension so that it has less air intake from the bottom, in order to modify the aerodynamics and improve fuel consumption; At the same time, we can also modify the center of gravity of the vehicle depending on what terrain we want to use .

3. ANOVA (11)

In statistics, we find the concept of Analysis of Variance (ANOVA), which consists of a grouping of statistical models and their associated procedures, where the variance is partitioned into certain components, due to various explanatory variables. If we break down its acronym in English, ANOVA means: Analysis of Variance.

The Analysis of Variance (ANOVA) is a type of parametric test. This means that a series of assumptions must be fulfilled to apply it, and that the level of the variable of interest must be, at least, quantitative (that is, at least interval, for example the intellectual coefficient, where there is a relative 0).

Variance analysis techniques

The first variance analysis techniques were developed in the '20s and' 30s by RA Fisher, a statistician and geneticist. That is why the Analysis of Variance (ANOVA) is also known as " Fisher's Anova " or "Fisher's analysis of variance"; This is also due to the use of Fisher's F distribution (a probability distribution) as part of the hypothesis contrast.

The analysis of variance (ANOVA) arises from the concepts of linear regression. Linear regression, in statistics, is a mathematical model that is used to approximate the dependence relationship between a dependent variable Y, independent variables Xi (for example different treatments) and a random term.

Role of this parametric test

Thus, an analysis of variance (ANOVA) serves to determine if different treatments (for example, psychological treatments) show significant differences, or if, on the contrary, it can be established that their average populations do not differ (they are practically the same, or their difference is not significant).

That is, ANOVA is used to test hypotheses about differences in means (always more than two). The ANOVA implies an analysis or decomposition of the total variability; This, in turn, can be attributed mainly to two sources of variation:

- Intergroup Variability
- Intragroup variability or error

Types of ANOVA

There are two types of analysis of variance (ANOVA):

<u>1. ANOVA I</u>

When there is only one classification criterion (independent variable; for example, type of therapeutic technique). In turn, it can be intergroup (there are several experimental groups) and intragroup (there is only one experimental group).

2. ANOVA II

In this case, there is more than one classification criterion (independent variable). As in the previous case, this can be intergroup and intragroup.

Characteristics and assumptions

When the analysis of variance (ANOVA) is applied in experimental studies, each group consists of a certain number of subjects, and the groups may differ in terms of this number. When the number of subjects coincides, we speak of a balanced or balanced model.

In statistics, to be able to apply the analysis of variance (ANOVA) a series of assumptions must be fulfilled:

1. Normality

This means that the scores in the dependent variable must follow a normal distribution. This assumption is verified by the so-called goodness of fit tests.

2. Independence

It implies that there is no autocorrelation between the scores, that is, the existence of independence of the scores from each other. To ensure compliance with this assumption, we must perform a MAS (simple random sampling) to select the sample that we are going to study or on which we are going to work.

3. Homocedasticity

This term means "equality of variances of subpopulations. " The variance is a statistic of variability and dispersion, and increases the greater the variability or dispersion of the scores.

The homoscedasticity assumption is checked by the Levene test or the Barlett test. If you do not comply, another alternative is to perform a logarithmic transformation of the scores.

Other assumptions

The above assumptions must be met when intergroup analysis of variance (ANOVA) is used. However, when using an intragroup ANOVA, the above assumptions and two more must be met:

1. Sphericity

If it is not met, it would indicate that the different sources of error correlate with each other. A possible solution if that happens is to perform a MANOVA (Multivariate Analysis of Variance).

2. Additivity

It involves non-interaction subject x treatment; if it is breached it would swell the error variance.

4. Taguchi method (10)

Gen'ichi Taguchi, a Japanese statistician and engineer, was one of the most important characters in the development of statistical techniques for the improvement of manufacturing processes. Taguchi was the main propellant of what is known as **Robust Engineering,** a method that points to a **reduction in the variability** of process *outputs.* Historically, it was sought to reduce the variability of processes through the elimination of the sources of noise that produced it, something quite utopian and complex to perform. The **Taguchi Method,** on the other hand, is based on eliminating or minimizing the effects of noise, and not the noise itself.

The variability of the processes is caused by parameters that cannot be controlled. These parameters are known as **process noises.** The **Design of Experiments** (DOE**,** for the initials in English of *Design of Experiments)* is a discipline that allows to analyse what effects the noises cause in the processes of quantitative way. This cause-effect relationship is modelled through a functional relationship, which is achieved with experimental help. The information obtained empirically allows us to understand the 'weight' of each noise source on the variability of the process. Many noise parameters may have considerable effects, some mild, and other negligible.

Taguchi was also the creator of the concept of **quality engineering,** which includes **quality control online** and **offline** (online and *offline)*. The online control includes all process control and maintenance activities, generally supported by the use of control charts. Offline control is a somewhat more innovative concept and is used in the design stage of the products and processes involved. The technique used in this case is the DOE.

Steps for Design of Experiments

The DOE is based on empirical data. These can be obtained if the following fundamental steps are followed:

- The objective of the analysis is defined, in terms of scope, costs and purpose.
- A work team is formed for the improvement project through DOE.
- The problem is specifically specified. You can use some problem analysis technique, such as Ishikawa or Pareto Diagrams, whose data can be obtained from a *brainstorming.*
- The technical and human environment is evaluated.
- The measurement system is defined and validated.
- The DOE is constructed, through feasibility tests and specific work procedures.
- The essays are prepared.

- The tests are executed.

- The tests are measured.

- The results are analyzed, discriminating noise signal, and modeling is performed.
- The optimum values of the parameters are chosen.
- New experiences are made to confirm.
- The results are reported.
- The progress made is compared with the objectives set out in the first points.

The Taguchi Quality Loss Function

The Taguchi Quality Loss Function allows us to calculate and quantify how much we move away from the expected (objective) value of a particular parameter. This valuation is done in monetary units. The further the parameter is from the expected value (target or *target)*, the greater the associated monetary loss that is transferred to the customer.

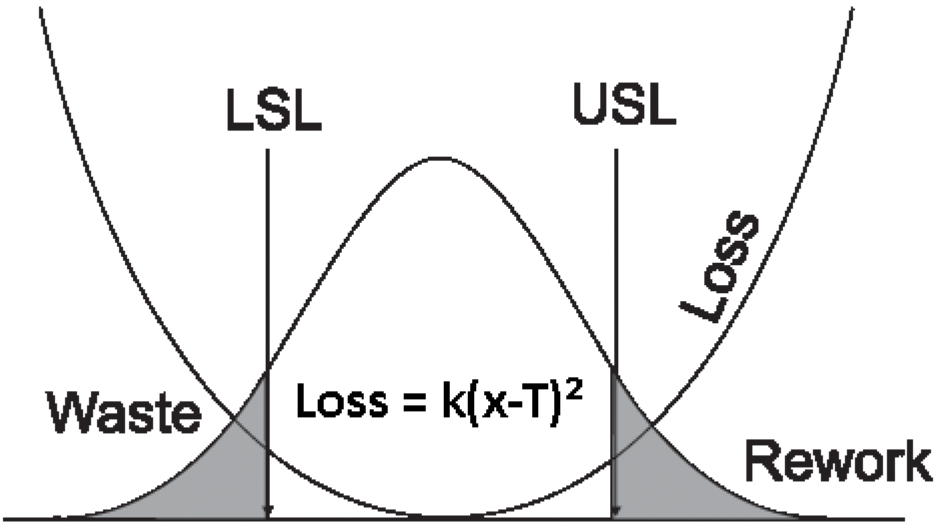


Figure 12. Taguchi quality loss function

This growth is exponential and is defined by the following equation:

$L(x) = k \cdot (x - T)^2$

where *L (x)* is the result of the loss function, *x* the value of the characteristic analysed, *T* its expected value and *k* a conversion constant to monetary units. Therefore, if *L = 0* , we are facing the expected quality. As *L* moves away from 0, in any sense, we are losing quality and increasing costs. There are tolerance limits, where L takes a maximum allowed value: the Lower Specification Limit and the Upper Specification Limit. A difference is observed with the traditional tolerance approach, in which it is considered that within the limits there is no loss.

5. Methodology

A typical shock absorber is composed of many elements as shown on Figures 13 to 28 (see annex 1) (1):

In this study, author is going to prepare a model of a RC shock absorber to analyse the optimal **flowrate** (Q) of silicone oil used as working fluid. The damper has several elements but the magnetic piston (or drilled plate, figure 13) is the target of this study. Actually, it is manufactured in aluminium but the author has developed the analysis using 3d printing FDM technology as the easiest way to build the elements and perform the necessary measures of the flowrate described below.

However, lectors must note that a larger flowrate does not mean better functionality of the damper (8). A huge flowrate means better shock absorption but RC vehicle body may suffers several impacts during its use. Because of that, the optimal solution has to offer good shock absorption within make the RC vehicle too flexible during impact.
According to find that solution, the author of present study has to compare flowrate measures with a quantitative variable that represents the general behaviour of the damper: **average damping coefficient** (ADC).

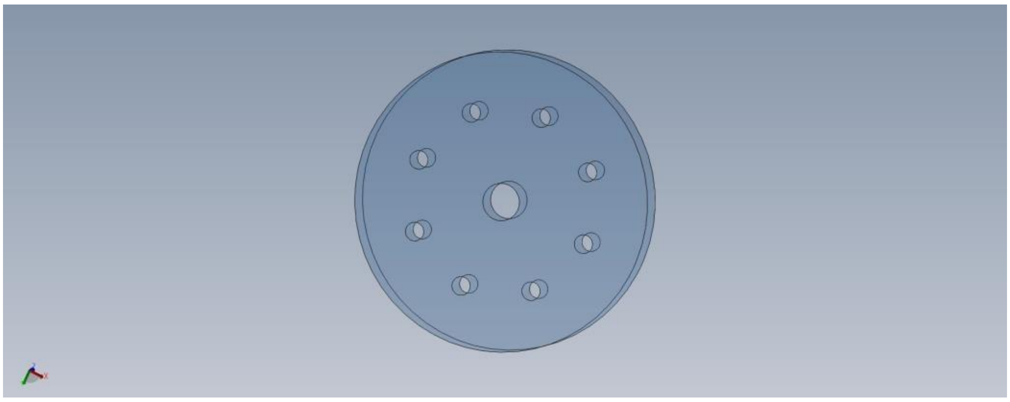


Figure 13. Magnetic piston

In the present work, an orthogonal design of experiments (DOE) was carried out to perform Q/ADC analysis. Parameters of the study are declared in Table 1. In order to measure the flowrate through the drilled plates (called as magnetic piston above), a model was built using the elements shown on figure 14.

Table 1. Factors and levels of DOE

Parameter	Level 1	Level 2	Level 3	Level 4
Perimeter holes diameter (PHD), mm	1.5	2	2.5	3
Centre hole diameter (CHD), mm	3	4	5	6
Hole length (HL), mm	2	3	4	5

Drilled plates was designed using 3D BUILDER (MICROSOFT) software and 3d printed by 3d printing system ARTILLERY X1 SIDEWINDER. Drilled plates models are shown on detail on figure 15. They were printed on PLA (polylactic acid) material, with 0.2mm layer height, 0.4mm brass nozzle diameter and 100% infill percentage.

Table 2. Taguchi design L16

Specimen	*PHD*	*CHD*	*HL*
1	1.5	3	2
2	1.5	4	3
3	1.5	5	4
4	1.5	6	5
5	2	3	3
6	2	4	2
7	2	5	5
8	2	6	4
9	2.5	3	4
10	2.5	4	5
11	2.5	5	2
12	2.5	6	3
13	3	3	5
14	3	4	4
15	3	5	3
16	3	6	2

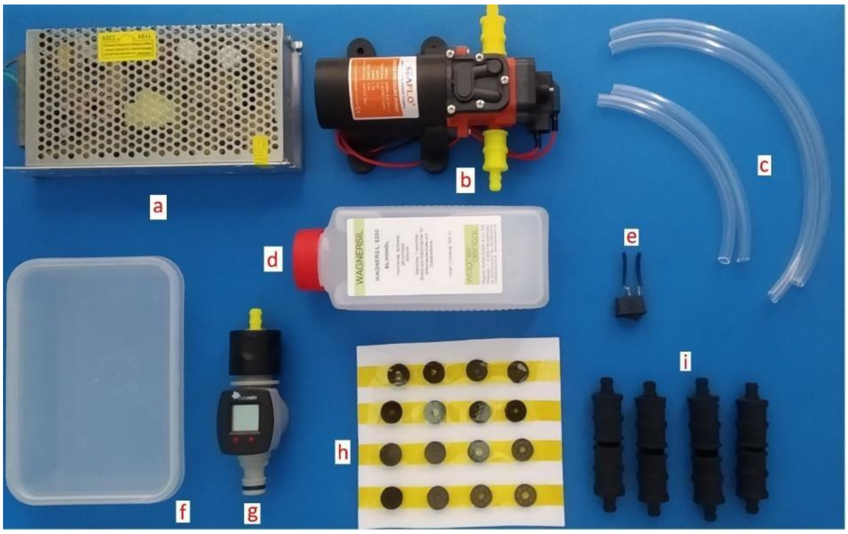


Figure 14. Elements used on model built-in: (a) Power supply 12v (b) Oil/water Pump 12v 2.4 bar (c) Connection Pipes (d) Silicone oil WAGNERSIL S200 500ML (e) Switch (f) Oil container 500 ML (g) Flowrate counter NATRAIN (h) Drilled plates (i) Couplers

Figure 15. Detailed picture of drilled plates manufactured by 3d printing AM method. Flowrate was measured using NATRAIN partial counter. This device registers total litres as absolute variable. The author used an interval of 25 seconds in order to calculate the flowrate through the system. Final model is presented on figure 16.

Figure 16. Final mounted model

On the other hand, damper system has been tested for each configuration of magnetic piston (drilled plate) in order to measure the relation between force and speed to represent the different "characteristic curves" and obtain the average damping coefficient as described in Damping tips (9)(5). To do this, author has tested each configuration in a damping test bench (figure 17). That system allows to register the pressure and time for each specimen.

Test bench operation is described below:
The power line is connected to the laboratory compressed air pipe (80psi). The intake valve regulates the pressure of the air entering the system. The user recorded the air pressure inside the system. Valve 5/2 has two positions. In one way, pressurized air enters the connected line at the top of the pneumatic cylinder been opened to the atmosphere the connected line at the bottom of the cylinder. At the other position of the valve, the bottom line is pressurized and the upper line is opened to the atmosphere. When the top line is pressurized, the pneumatic cylinder exerts a constant force that compresses the damper. The upper grip then moves at constant speed. To determine this speed, the stopwatch buttons are used to record the time it takes for the top grip to travel the distance that separates the pushbuttons. Also, when the bottom line is pressurized, the pneumatic cylinder exerts a constant force that extends the damper.

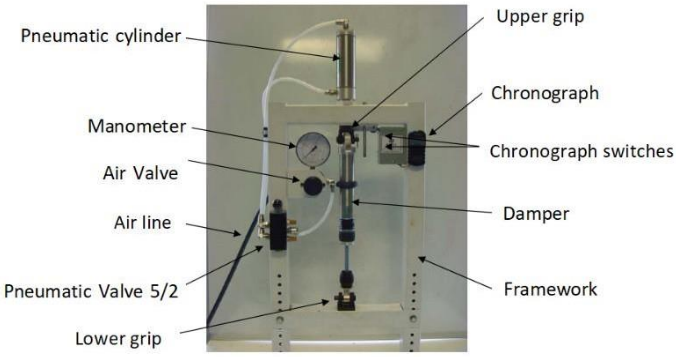


Figure 17. Test bench

The values of flowrate (Q) and average damping coefficient (ADC) were analysed using MINITAB software, performing a statistical analysis of these parameters according to Taguchi method and analysis of variance (ANOVA). The author has measured Q and ADC variables a total of 5 times for each drilled plate.

6. Results

The measured values of flowrate Q and ADC are presented in Tables 3.1 and 3.2. These values were calculated as the arithmetic mean of the measurements (MINITAB software) for each drilled plate. This data is used to perform a Taguchi analysis and ANOVA checking results. These analyses are presented in Figures 18 to 20 and table 5.

According to estimate the ADC parameter for each specimen, the analysis of force and speed as described below was performed. Results of these variables are presented on Tables 4.1 and 4.2.

Table 3.1. Results of flowrate Q for each specimen

Specimen	Measure 1 Q(L/s)x10^3	Measure 2 Q(L/s)x10^3	Measure 3 Q(L/s)x10^3	Measure 4 Q(L/s)x10^3	Measure 5 Q(L/s)x10^3	Mean
1	1,074	1,12	1,13	0,983	1,112	1,0838
2	1,43	1,545	1,543	1,345	1,654	1,5034
3	1,55	1,55	1,655	1,479	1,64	1,5748
4	1,754	1,7	1,89	1,843	1,876	1,8126
5	1,97	1,89	1,95	1,992	1,99	1,9584
6	2,12	2,05	2,34	2,223	2,21	2,1886
7	2,33	2,43	2,23	2,233	2,43	2,3306
8	2,56	2,654	2,66	2,578	2,679	2,6262
9	2,78	2,94	2,95	2,88	2,765	2,863
10	3,01	3,12	3,03	3,11	3,2	3,094
11	3,28	3,34	3,33	3,34	3,49	3,356
12	3,77	3,75	3,94	3,88	3,811	3,8302
13	4,24	4,33	4,241	4,32	4,223	4,2708
14	5,56	5,472	5,6	5,588	5,599	5,5638
15	5,98	6,01	6,1	6,05	6,1	6,048
16	6,87	6,89	7	7,2	7,11	7,014

Table 3.2. Results of average damping coefficient (ADC) for each specimen

Specimen	ADC on traction mode	ADC on compression mode
1	2016	3457,46968
2	2184,4	3386,60263
3	1992,8	3706,28761
4	2103,92	3901,00285
5	1663,2	2949,00053
6	1520	2820,185
7	1521	2994,48385
8	1436,4	2790,17857
9	1241,68	2435,20365
10	1171,2	2492,2557
11	1258,56	2577,76498
12	1254	2606,42919
13	925,6	1926,07704
14	972	1792,01434
15	1008	1886,35169
16	936,32	1819,01384

Table 4.1. Results for force, time and speed of each hydraulic damper configuration on compression mode

Specimen	Force, F (N)	Time 1 (s)	Time 2 (s, x10)	Damper travel (m, x10^3)	Speed (m/s, x10^3)
1	402	0	2,15	25	116,27
2	409	0	2,07	25	120,77
3	425	0	2,18	25	114,67
4	424	0	2,3	25	108,69
5	388	0	1,9	25	131,57
6	375	0	1,88	25	132,97
7	380	0	1,97	25	126,9
8	375	0	1,86	25	134,4
9	342	0	1,78	25	140,44
10	354	0	1,76	25	142,04
11	358	0	1,8	25	138,88
12	360	0	1,81	25	138,12
13	321	0	1,50	25	166,66
14	320	0	1,4	25	178,57
15	323	0	1,46	25	171,23
16	318	0	1,43	25	174,82

Table 4.2. Results for force, time and speed of each hydraulic damper configuration on traction mode

Specimen	Force, F (N)	Time 1 (s)	Time 2 (s, x10)	Damper travel (m, $x10^3$)	Speed (m/s, $x10^3$)
1	210	0	2,4	25	104,16
2	215	0	2,54	25	98,42
3	212	0	2,35	25	106,38
4	221	0	2,38	25	105,04
5	198	0	2,1	25	119,04
6	190	0	2	25	125
7	195	0	1,95	25	128,2
8	190	0	1,89	25	132,27
9	187	0	1,66	25	150,6
10	183	0	1,6	25	156,25
11	184	0	1,71	25	146,19
12	190	0	1,65	25	151,51
13	178	0	1,3	25	192,3
14	180	0	1,35	25	185,78
15	180	0	1,4	25	178,57
16	176	0	1,33	25	187,96

Taguchi analysis results:

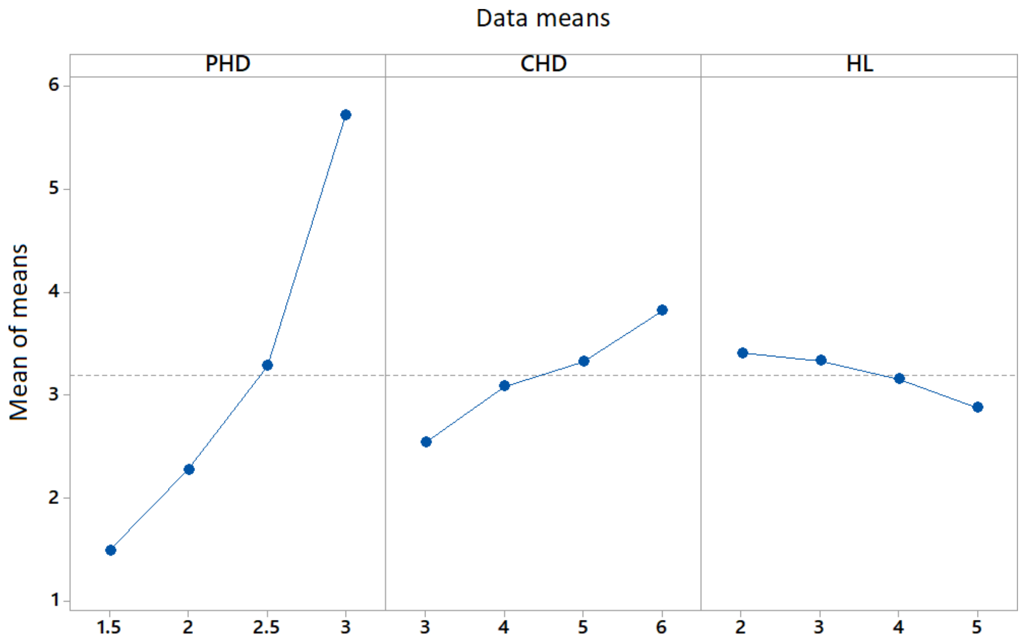


Figure 18. Mean of means diagram for Q (flowrate, L/s x 10^3)

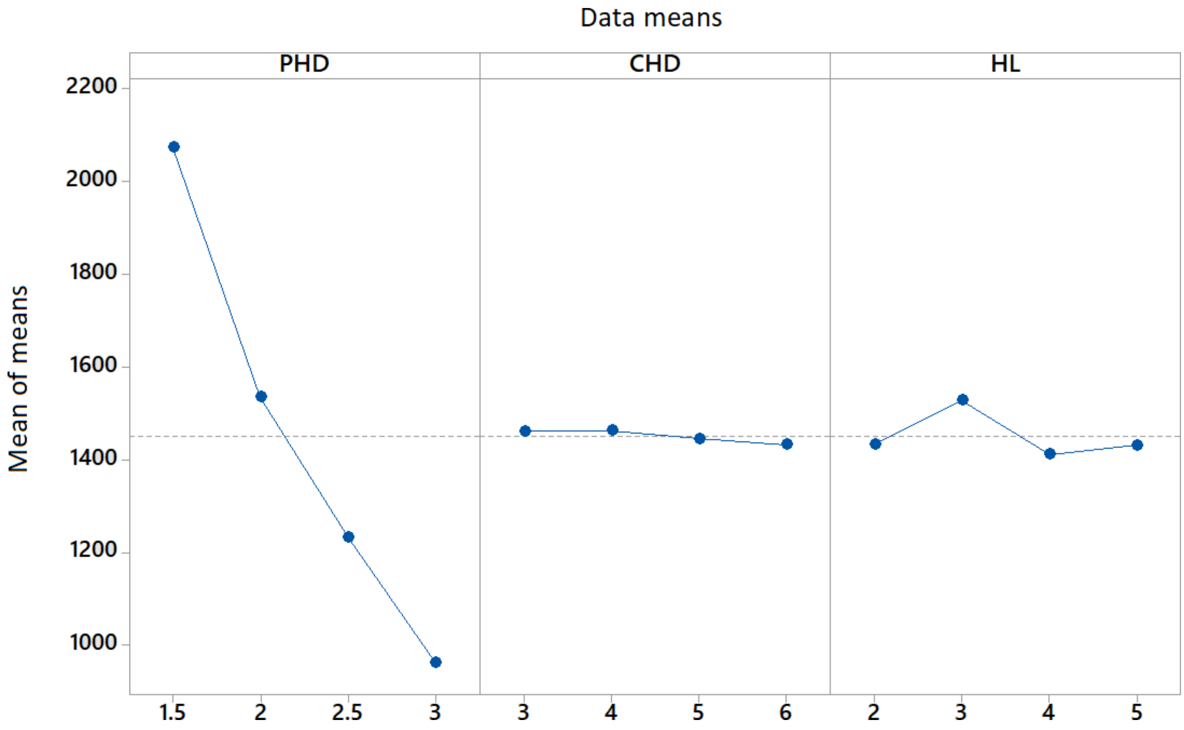


Figure 19. Mean of means diagram for ADCt (average damping coefficient on traction mode, Ns/m)

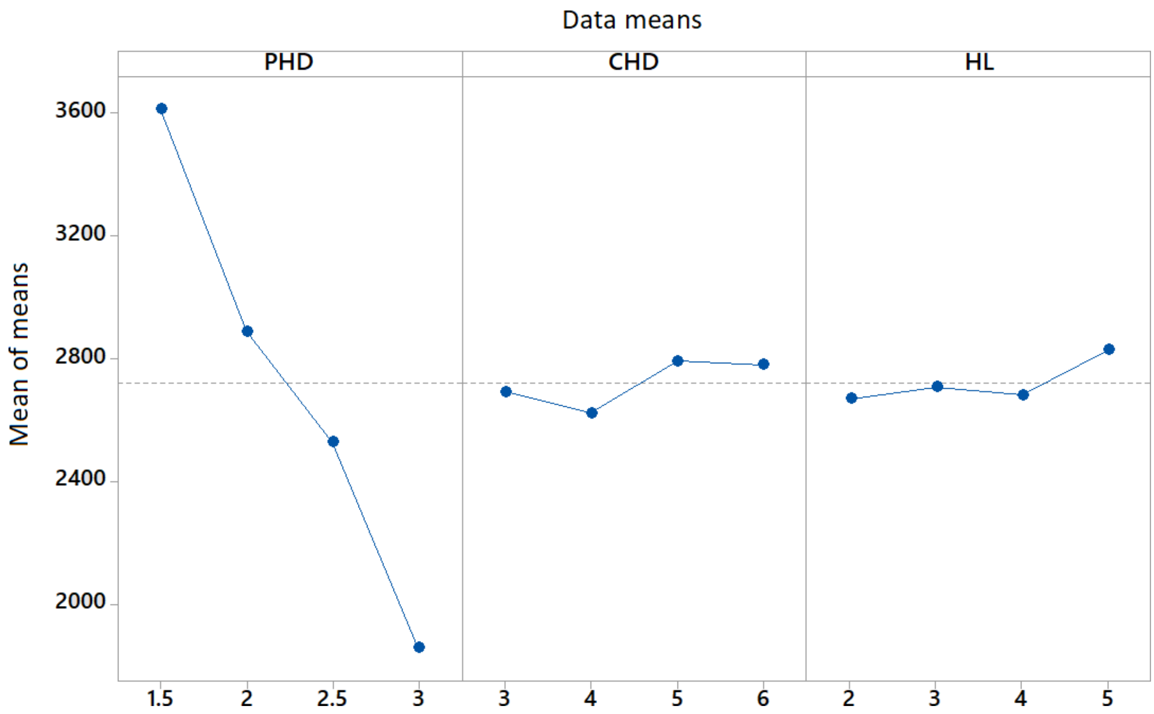


Figure 20. Mean of means diagram for ADCc (average damping coefficient on compression mode, Ns/m)

Table 5. Results for Q (flowrate), ADCt (average damping coefficient on traction mode) and ADCc (average damping coefficient on compression mode)

Specimen	Q (flowrate, L/s x 10^3)	ADCt (traction mode) (Ns/m)	ADCc (compression mode) (Ns/m)
1	1,0838	2016	3457,46968
2	1,5034	2184,4	3386,60263
3	1,5748	1992,8	3706,28761
4	1,8126	2103,92	3901,00285
5	1,9584	1663,2	2949,00053
6	2,1886	1520	2820,185
7	2,3306	1521	2994,48385
8	2,6262	1436,4	2790,17857
9	2,863	1241,68	2435,20365
10	3,094	1171,2	2492,2557
11	3,356	1258,56	2577,76498
12	3,8302	1254	2606,42919
13	4,2708	925,6	1926,07704
14	5,5638	972	1792,01434
15	6,048	1008	1886,35169
16	7,014	936,32	1819,01384

ANOVA results:

ANOVA: Q vs. PHD

Method

Null hypothesis All means are equal

Alternate hypothesis No All means are equal

Level of significance α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
PHD	4	1.5; 2; 2.5; 3

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
PHD	3	40,576	13,5255	32,90	0,000
Error	12	4,934	0,4112		
Total	15	45,510			

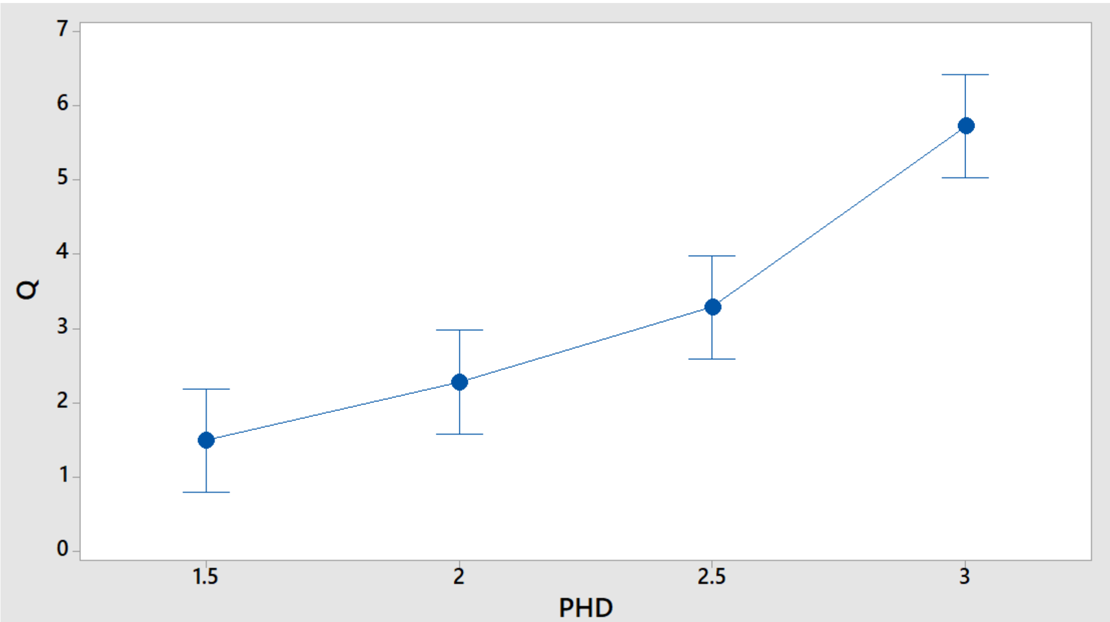
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
0,641216	89,16%	86,45%	80,73%

Means

PHD	N	Mean	Desv.Est.	IC de 95%
1.5	4	1,494	0,304	(0,795; 2,192)
2	4	2,276	0,279	(1,577; 2,974)
2.5	4	3,286	0,415	(2,587; 3,984)
3	4	5,724	1,141	(5,026; 6,423)

Agrouped est. dev. = 0,641216



Q vs. CHD

Method

Null hypothesis All means are equal

Alternate hypothesis No All means are equal

Level of significance α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
CHD	4	3; 4; 5; 6

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
CHD	3	3,378	1,126	0,32	0,810
Error	12	42,132	3,511		
Total	15	45,510			

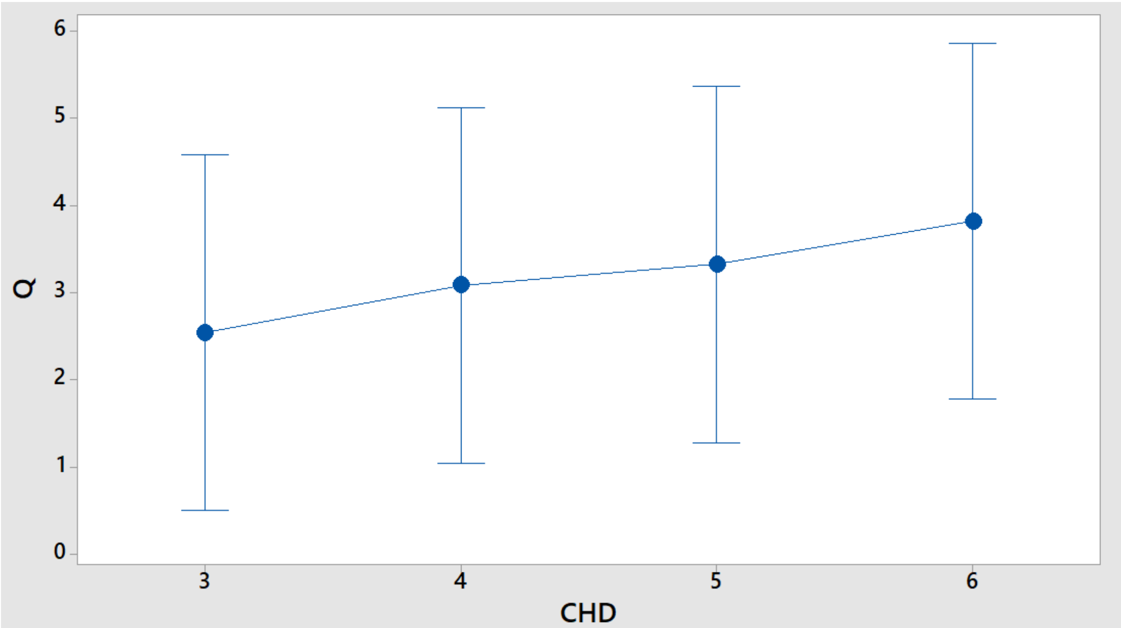
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
1,87378	7,42%	0,00%	0,00%

Means

CHD	N	Mean	Desv.Est.	IC de 95%
3	4	2,544	1,361	(0,503; 4,585)
4	4	3,087	1,775	(1,046; 5,129)
5	4	3,327	1,955	(1,286; 5,369)
6	4	3,82	2,28	(1,78; 5,86)

Agrouped est. dev. = 1,87378



Q vs. HL

Method

Null hypothesis	All means are equal
Alternate hypothesis	No All means are equal
Level of significance	α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
HL	4	2; 3; 4; 5

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
HL	3	0,6746	0,2249	0,06	0,980
Error	12	44,8356	3,7363		
Total	15	45,5102			

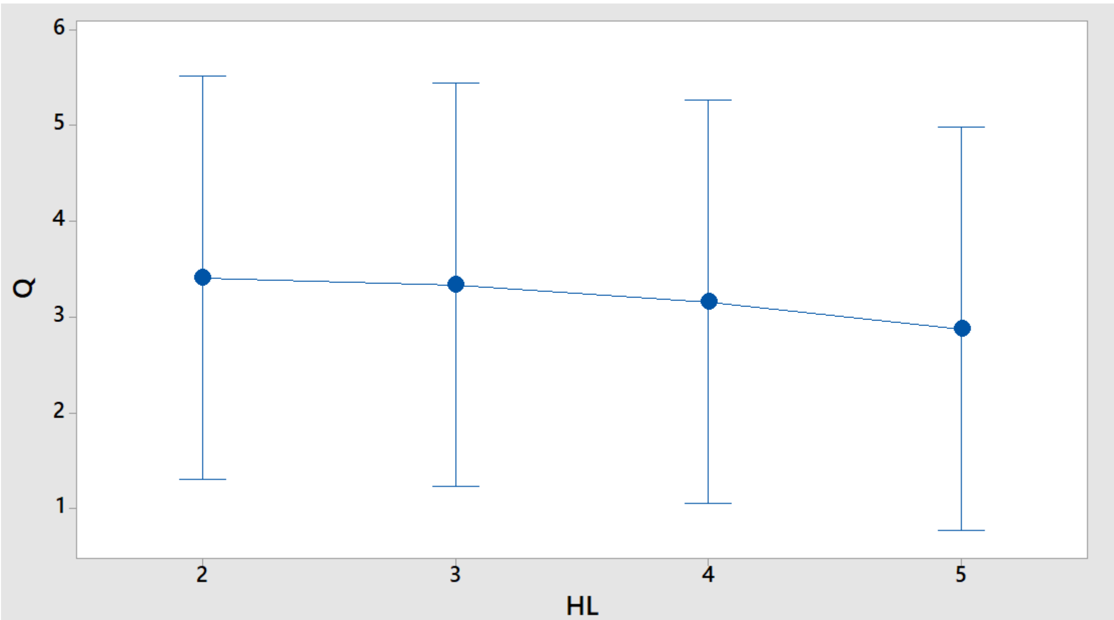
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
1,93295	1,48%	0,00%	0,00%

Means

HL	N	Mean	Desv.Est.	IC de 95%
2	4	3,41	2,58	(1,30; 5,52)
3	4	3,34	2,07	(1,23; 5,44)
4	4	3,157	1,699	(1,051; 5,263)
5	4	2,877	1,068	(0,771; 4,983)

Agrouped est. dev. = 1,93295



ADCt vs. PHD

Method

Null hypothesis	All means are equal
Alternate hypothesis	No All means are equal
Level of significance	α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
PHD	4	1.5; 2; 2.5; 3

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
PHD	3	2737636	912545	186,27	0,000
Error	12	58788	4899		
Total	15	2796424			

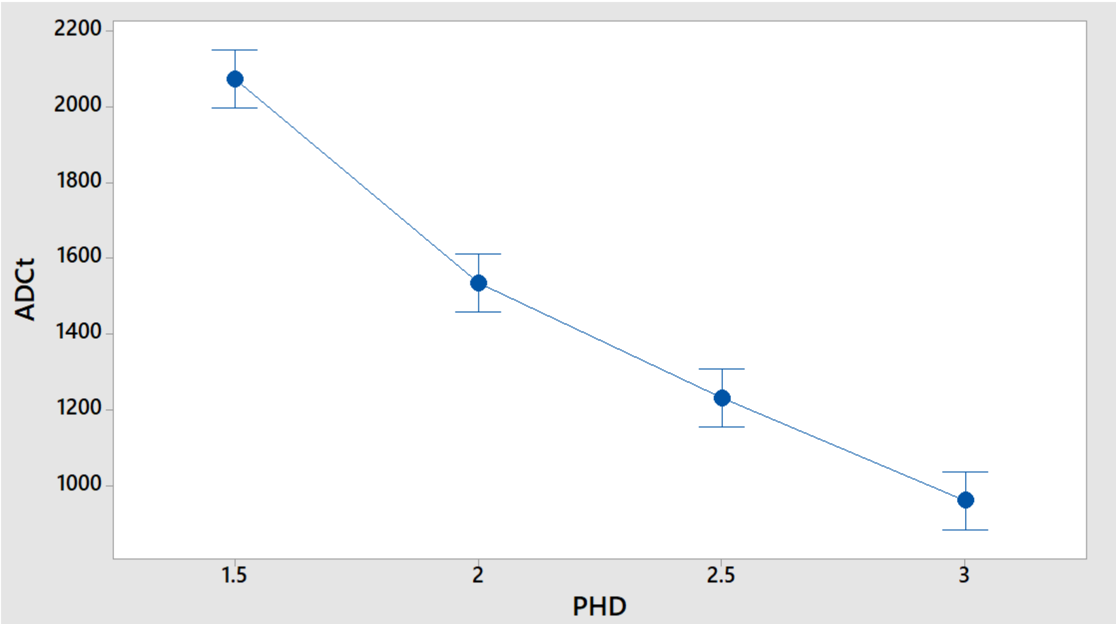
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
69,9928	97,90%	97,37%	96,26%

Means

PHD	N	Mean	Desv.Est.	IC de 95%
1.5	4	2074,3	87,6	(1998,0; 2150,5)
2	4	1535,1	94,1	(1458,9;1611,4)
2.5	4	1231,4	40,7	(1155,1; 1307,6)
3	4	960,5	37,4	(884,2; 1036,7)

Agrouped est. dev. = 69,9928



ADCt vs. CHD

Method

Null hypothesis All means are equal

Alternate hypothesis No All means are equal

Level of significance α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
CHD	4	3; 4; 5; 6

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
CHD	3	2404	801	0,00	1,000
Error	12	2794020	232835		
Total	15	2796424			

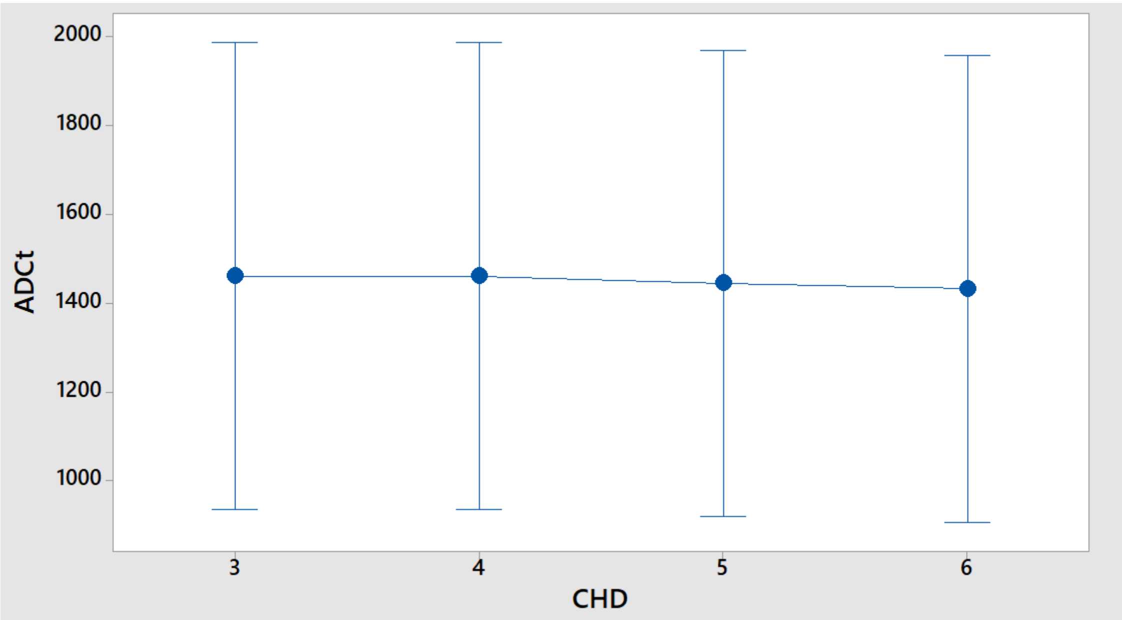
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
482,530	0,09%	0,00%	0,00%

Means

CHD	N	Mean	Desv.Est.	IC de 95%
3	4	1462	477	(936; 1987)
4	4	1462	532	(936; 1988)
5	4	1445	421	(919; 1971)
6	4	1433	493	(907; 1958)

Agrouped est. dev. = 482,530



ADCt vs. HL

Method

Null hypothesis All means are equal

Alternate hypothesis No All means are equal

Level of significance α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
HL	4	2; 3; 4; 5

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
HL	3	32859	10953	0,05	0,986
Error	12	2763564	230297		
Total	15	2796424			

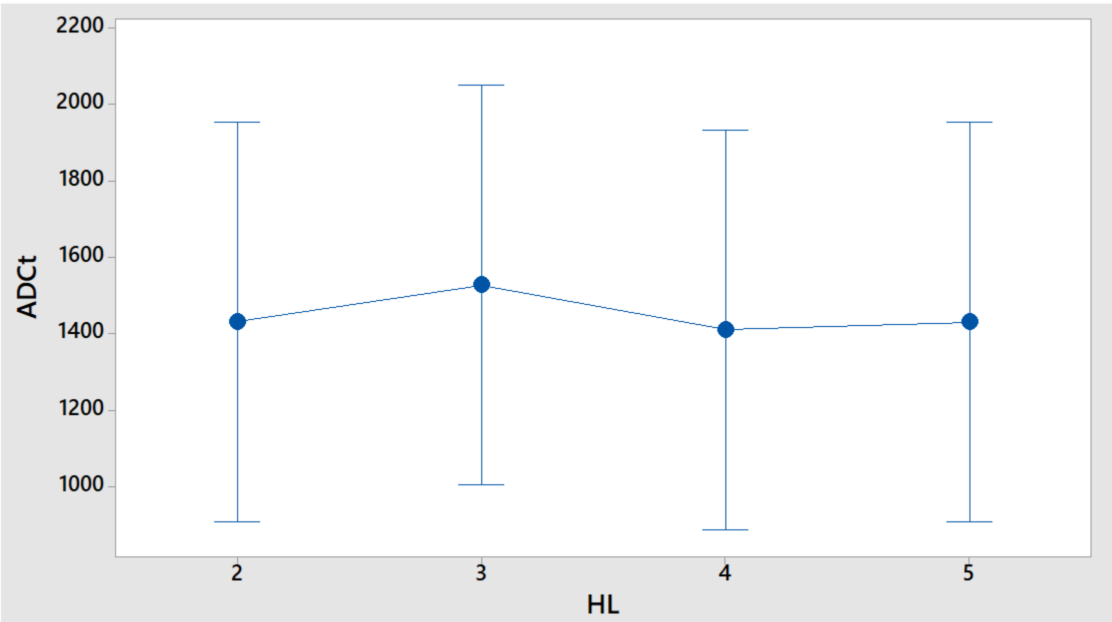
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
479,893	1,18%	0,00%	0,00%

Means

HL	N	Mean	Desv.Est.	IC de 95%
2	4	1433	456	(910; 1956)
3	4	1527	515	(1005; 2050)
4	4	1411	432	(888; 1934)
5	4	1430	511	(908; 1953)

Agrouped est. dev. = 479,893



ADCc vs. PHD

Method

Null hypothesis	All means are equal
Alternate hypothesis	No All means are equal
Level of significance	α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
PHD	4	1.5; 2; 2.5; 3

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
PHD	3	6436662	2145554	113,86	0,000
Error	12	226131	18844		
Total	15	6662793			

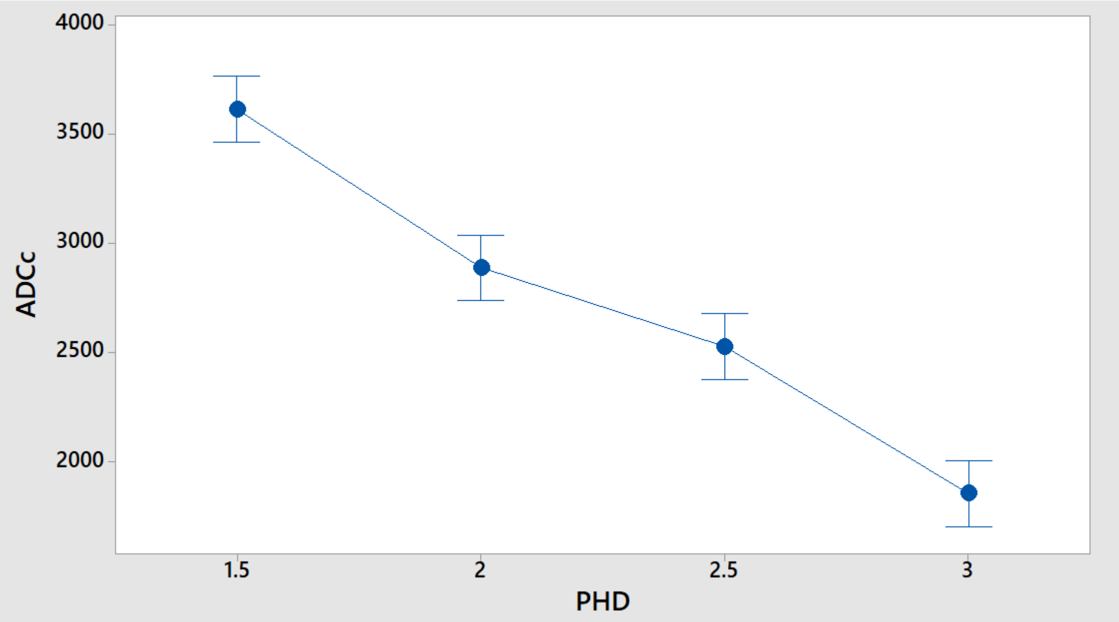
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
137,274	96,61%	95,76%	93,97%

Means

PHD	N	Mean	Desv.Est.	IC de 95%
1.5	4	3613	236	(3463; 3762)
2	4	2888,5	98,7	(2738,9; 3038,0)
2.5	4	2527,9	78,6	(2378,4; 2677,5)
3	4	1855,9	61,4	(1706,3; 2005,4)

Agrouped est. dev. = 137,274



ADCc vs. CHD

Method

Null hypothesis	All means are equal
Alternate hypothesis	No All means are equal

Level of significance α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
CHD	4	3; 4; 5; 6

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
CHD	3	75231	25077	0,05	0,986
Error	12	6587561	548963		
Total	15	6662793			

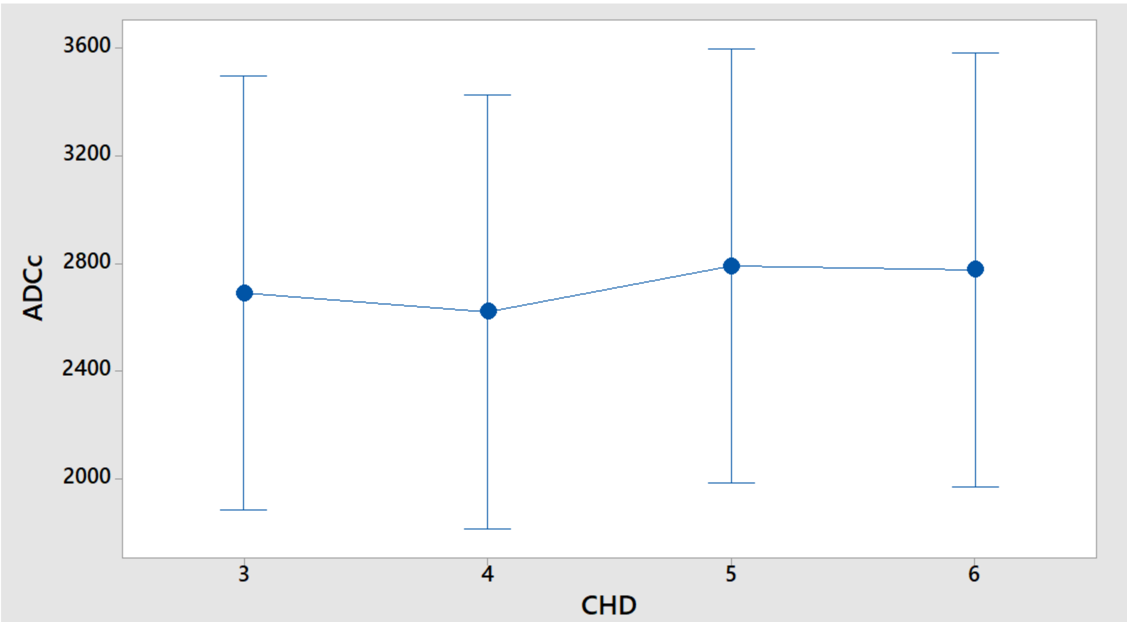
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
740,921	1,13%	0,00%	0,00%

Means

CHD	N	Mean	Desv.Est.	IC de 95%
3	4	2692	659	(1885; 3499)
4	4	2623	666	(1816; 3430)
5	4	2791	762	(1984; 3598)
6	4	2779	858	(1972; 3586)

Agrouped est. dev. = 740,921



ADCc vs. HL

Method

Null hypothesis	All means are equal
Alternate hypothesis	No All means are equal
Level of significance	α = 0,05

Suposed equal variance .

Factor info

Factor	Levels	Values
HL	4	2; 3; 4; 5

Variance analysis

Prod	GL	SC Ajust.	MC Ajust.	Value F	Value p
HL	3	64363	21454	0,04	0,989
Error	12	6598430	549869		
Total	15	6662793			

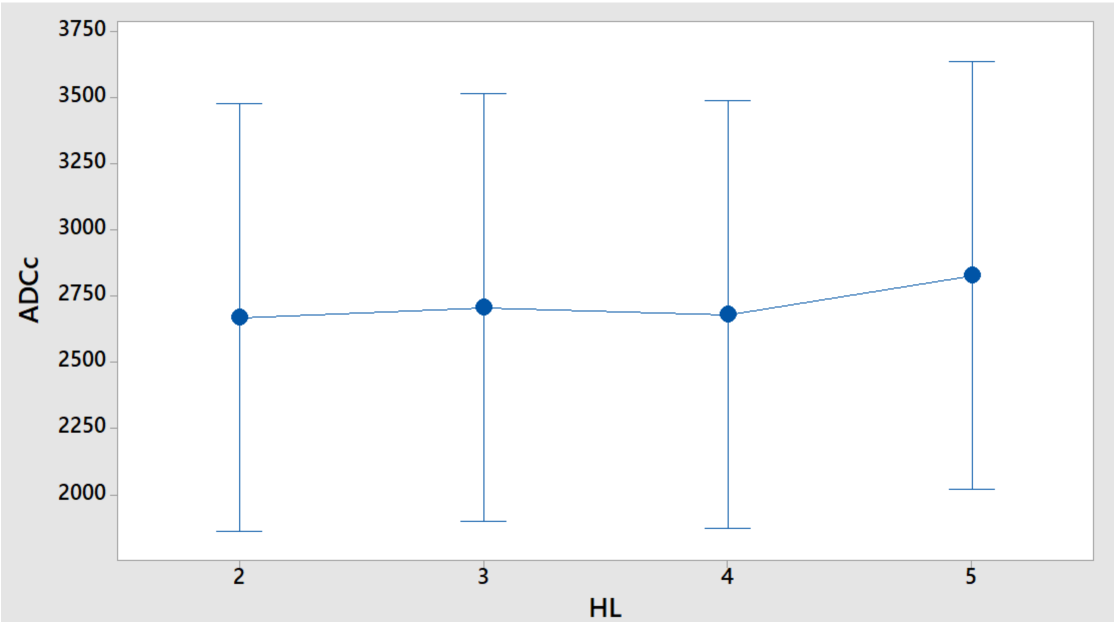
Model resumen

S	R-cuad.	R-cuad. (adjusted)	R-cuad. (pred)
741,532	0,97%	0,00%	0,00%

Means

HL	N	Mean	Desv.Est.	IC de 95%
2	4	2669	677	(1861; 3476)
3	4	2707	634	(1899; 3515)
4	4	2681	799	(1873; 3489)
5	4	2828	838	(2021; 3636)

Agrouped est. dev. = 741,532



7. Conclusions

From the above data, a decrease in mean damping coefficients in both modes and fluid flow as perimeter perforations become smaller, with the PHD factor being the most decisive in the experiment.

Thus, we can establish that the performance of the shock is hard in the event that the magnetic piston has perforations of between 1.5 and 2mm, typical of a sportier and more necessary ride in terrain of few obstacles. In the case of a driving with comfort needs or a circuit with jumps and obstacles in the field, a diameter of 2.5 and 3 mm should be used.

Given the common use of these vehicles, the study author concludes that part 4 may be the most suitable due to its large balance between damping coefficients and necessary oil flow.

8. Future Works.

We can use this analysis for a future race competition, so we will try in a differents tracks and will see (time-lap) after differents trainings, in actuality we can try for a expecional situation, we can´t go to the tracks for try , but we will use with some driver RC Cars.

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ANNEX 1:

COSTS ESTIMATION SUMMARY

TASK/PRODUCT	UNIT	QUANTITY	TOTAL (€)
PROJECT LEAD FEES	H	120	1800
PROJECT ASSOCIATES FEES	H	15	225
3D FILAMENT	Kg	0,1	5
3D PRINTER ELECTRICAL CONSUMPTION	H	15	12
WATER/OIL PUMP 12 V	-	1	23
POWER SUPPLY 12V	-	1	24
FLOWRATE COUNTER NANTRAIN	-	1	17
PP HOSES	M	2	15
SILICONE OIL WAGNERSIL S200	-	1	23
OIL CONTAINER	-	1	3
3D PRINTED PARTS	-	8	35
40X100 WOOD TABLE	-	1	12
TEST BENCH RENTING	H	30	600
			2794€

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de Terrassa

ANNEX 2: ENVIROMENTAL IMPACT STUDY

GENERAL DATA

a. Project Title: Statistical Analysis of Silicone Oil Flow through drilled plates used in RC cars

b. Project Promoter: Alejandro Brujas Llimargas

c. Responsible for carrying out the environmental impact: Alejandro Brujas Llimargas

d. Project type: NEW

IMPACT IDENTIFICATION

No type of environmental impact is foreseen due to the preparation of this study and the construction and testing of the models, with the exception of the use of silicone oil as a working fluid.

The recycling procedure and the technical specifications of the product characteristics are presented below:

IMPACT 1: WAGNERSIL S200 silicone oil

- Synthetic lubricating oil for high working temperatures.

- This product is not considered toxic or dangerous according to RD-1078/93 and Directive 88/379 / CEE and its subsequent updates (Order of 20.02.95, BOE 46 of 23.02.95; Directive 93/18 / CEE of 05.04. 93; Directive 1999/45 / CE; RD-255/2003).

First aid:

- Skin contact: wash with soap and water. Do not use solvents.
- Eye contact: wash with plenty of water for at least 15 minutes. In case of irritation, see a doctor.
- Inhalation: normally no first aid measure is required. In case of discomfort, move to a fresh air area.
- Ingestion: do not induce vomiting. Seek medical assistance. Do not try to make an unconscious person eat anything.

Fire-fighting measures:

- Suitable extinguishing media: foam. CO2 dry chemical powder. Water spray to cool containers exposed to fire.
- Extinguishing media not allowed: water jet.

- Exposure risks: attention to products produced by thermal decomposition or combustion.
- Special protective equipment for personnel: wear complete equipment for chemical products and wear self-contained breathing apparatus.

Measures in case of accidental spillage:

- Individual precautions: none special. Avoid contact with skin and eyes.
- Precautions for the Environment: prevent contamination of soil, water and drains.
- Cleaning methods: collect with absorbent earth and / or mechanical means and deposit in a suitable container for recycling or disposal in accordance with current legislation.

Manipulation and storage:

- Handling: keep containers tightly closed to avoid spills or splashes. Avoid the formation of mists and vapors. Do not eat, drink, or smoke in the workplace.
- Storage: recommended in its original container and under cover. Keep containers closed.

Exposure controls / personal protection:

- Protection measures: no special measures are required.
- Respiratory protection: normally no special measures are required.
- Protection of hands: it is recommended to use suitable gloves.
- Eye protection: recommended to wear safety glasses.
- Skin protection: recommended to use the usual clothing in the chemical or mechanical industry.

Physical and chemical properties:

- Appearance: colorless oily liquid.
- Smell: odorless.
- Melting point: not applicable.
- Boiling point: greater than 300 Celsius.
- Flash point: greater than 300 Celsius (ASTM D-92).
- Self-flammability: approx. 450 Celsius.
- Solubility in water: insoluble.
- Density: approx. 0.965 to 15 Celsius.
- pH value: not applicable.
- Viscosity: approx. 350 cSt at 25 Celsius.

Stability and reactivity:

- Stability: the product is stable.
- Materials to avoid: strong oxidizing agents.
- Hazardous decomposition products: Thermal decomposition and combustion can produce carbon oxides and other toxic gases and vapors.

Ecological information:

The product is of low biodegradability. Do not pour into public channels. Avoid contamination of soil, water and drains. This does not have additional data on the ecotoxicity of the product.

Disposal considerations:

Eliminate waste and empty containers through authorized managers in waste treatment. Proceed according to the regulations in force.

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ANNEX 3: ECONOMIC ANALYSIS

The present study does not intend the sale of any product, good or service to the market, therefore, the market analysis and financial situation are inappropriate.

The test teams are from the University of Cordova.

ANNEX 4:

Regarding test standards and spreadsheets, they do not exist since they are made with Minitab.

ANNEX 5: GANTT CHART