Abstract
This project develops the design of a test for pressure switch for automation sector. The tests bench designed is able to check the exact pressure action of the switch, whether it is OK or not OK. It is able to regulate them (those that are designed with regulation option) and it is able to do a leak test. It has also a station for checking the thread height of these sensors.

This is a machine where a very large family of sensors have to being tested, geometrically variable and with very different pressures action, (from the 0.05 bars [relating] to 16 bars [relative]) we have used high precision devices (pressure controller, multiplier, controller type PLC, computer, electro valves...).

The machine has been designed from an ergonomic, simple, intuitive and secure view following the current regulations.

The machine is currently under construction by the company Francisco Albero S.A.U (FAE)

1. Introduction
Based on an outdated old machine, which is the one currently used to test the sensors, a totally new mechanism is designed to improve each and every defect found in the former, preserving the strengths pooled in a brainstorming carried out by the different departments of the company.

The lack of precision, the cycle time slow, the human error, the testing lack on the process, the high demand and the no information generated when testing and calibrating the sensors have produced the requirement of making a machine able to achieve all these objectives of the company. Throughout the document, the operation method of the sensors, the preliminary study conducted, the pre-design of the new machine and the final design of the new testing bench are fully explained and detailed, along with the improvement results obtained, the overall drawings of the machinery, the budget to undertake its construction and the specifications of the project.

The main objective of this project is to design a very simple and ergonomic machine to improve significantly the current cycle time, both with higher guarantees of reliability and accuracy.

2. Previous study
Several studies have been undertaken before the accomplishment of the new testing bench, starting by understanding and identifying the type of sensors to be checked and / or calibrated. The mano-contacts are pressure switches with different methods of action: they connect or disconnect an electrical circuit through the oil pressure in the tank of the vehicle, when it reaches a certain temperature.

Our machine cannot test the sensors with oil, since the pieces will get dirty, we will use pressurized air to carry out the process.

These sensors have been classified by the characteristics of each of the 186 different references going through the new machine, and a description of the operations that should be performed to check or regulate them has been made according to the group or family they belong to:

- Checking process.
- Calibration or adjustment process.
- Reversing light switch checking process.
- Hydraulic switch checking process.

As may be seen, the design of this new machine is also taken as an advantage to test other items which are very similar to pressure switches.

In this section, the design and the real functioning of the machine is also explained and detailed, a hand-operated bank with analogical devices and with no other external control rather than the worker’s operations.

The machine is started up with a hand lever (on the left of the Figure 2) and it can be pushed up to reach the desired pressure, which can be visually controlled through the analogical gauges until the red light goes on and off (depending on whether the sensor is connected or disconnected). In the central part of the Figure 2 there is a hinged locking system where sensors are placed to be checked and / or calibrated.
As I previously mentioned, in the preliminary study a brainstorming has been carried out thanks to the cooperation of different departments (quality, engineering, production and methodology and times), what enabled us to find out of the benefits, the drawbacks and the improvement measures to take into account in the new test bench design.

Then a comprehensive survey of the production in the past few years (2011-2014) has been also conducted to assess which skills the new machine has to achieve, following the expectations on the project.

### 3. Pre-design test bench

Once the statement with the requirements has been explained and the proceedings to test the sensors has been understood, it is time to start off the initial design of the new machine. Firstly, we made a selection of the current legal standards and regulations to comply with, both regarding the safety of the machinery as well as the environmental conditions (considering sustainability, hazardous wastes and recycling). The machine also must have the CE mark to be manufactured and used.


As the current regulations are very extensive and vague, we have relied on several Harmonised Standards that helped us to complement the existing legislation in this field and to create a much safer machine. In the memory document we provide a list of the Harmonized Regulations that have been used for the making of the machinery.

In the global design of the mechanism, the environmental perspective has also been taken into account, in compliance with the regulation UNE-EN ISO 14001: 1996, ENVIRONMENTAL MANAGEMENT SYSTEMS. SPECIFICATIONS WITH GUIDANCE FOR USE, where it is said that it will not use any material damaging the environment, neither in the manufacturing of the machine nor in the process of this. It also accomplish with the law of Royal Decree 952/97 of 20 June (which includes the list of hazardous waste adopted by Decision 94/904/EC of the Council of December 22, in accordance with paragraph 4 of Article 1 of Directive 91/689/EEC).

Thereupon, all the purchasing components as well as the manufactured and the assembly parts we need for the new design of the machine should be carefully selected.

In order to make an accurate choice of components, several calculations and endurance tests have been performed. We have calculated what will be the minimum section that the cylinders must have to withstand the maximum pressure to keep working, the maximum time needed to fill our tank with a multiplier (Figure 3) and we have also checked the reliability, accuracy and the cycle time of both models of MENSOR (Figure 3) through testing and benchmarking processes.

The pressure controller MENSOR has been tested with different programs in order to extract the minimum tolerances needed to measure the pressure of the sensors and find out the lowest cycle time.

One of the most important calculations we had to make was to find out the exact amount of force to be applied in form of pressure to the sensors, in order to sizing the cylinders that should act against it. To do this, we have chosen the sensor with the largest section (26, 8 mm ≈ 27 mm) and the maximum pressure that the multiplier can reach (24 bars), and from that point onwards the force has been calculated:

- First, the performance area of the Force:
  \[ A = \pi \cdot \left( \frac{D}{2} \right)^2 = \pi \cdot \left( \frac{26}{2} \right)^2 = 572.55 \, \text{mm}^2 \approx 572.6 \, \text{mm}^2 \]

- Then, the requested force:
  \[ F = 24 \, \text{bar} \cdot \frac{0.1 \, \text{N/mm}^2}{1 \, \text{bar}} \cdot 572.6 \, \text{mm}^2 = 1374.24 \, \text{N} \]

- Finally, the force with a safety factor (n=2):
  \[ F_r = 2 \times F = 2 \times 1374.24 = 2748.5 \, \text{N} \]

Bearing in mind this calculation, we looked for in the catalogue’s data sheet of the manufacturer (in this case FESTO) and we found out that the essential cylinder must have a plunger diameter of 80 mm at least to withstand the requested force.

To decide the specific functions these devices should meet, we rely on the mistakes of the current machine.

Finally, as being one of the most important goals both of our new test bench and the company itself, we
accomplished the demonstration of improvement with time cycles and the cost involved in this process. The cycle time for the new test bench increased in a 164% in the “testing” sensors type and a 45% in the “calibration” ones (Table 1): 

<table>
<thead>
<tr>
<th>TEST</th>
<th>WORK BENCH</th>
<th>PROCESS</th>
<th>TIME (s)</th>
<th>Pcs / h</th>
<th>% IMPROVED</th>
</tr>
</thead>
<tbody>
<tr>
<td>TESTING</td>
<td>OLD ONE</td>
<td>Favourable</td>
<td>11,4</td>
<td>316</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unfavourable</td>
<td>17,1</td>
<td>211</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NEW ONE</td>
<td>Favourable</td>
<td>7,98</td>
<td>902</td>
<td>164%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unfavourable</td>
<td>14,82</td>
<td>486</td>
<td></td>
</tr>
<tr>
<td>CALIBRATION</td>
<td>OLD ONE</td>
<td>Favourable</td>
<td>57</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unfavourable</td>
<td>119,7</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NEW ONE</td>
<td>Favourable</td>
<td>45,6</td>
<td>79</td>
<td>45%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Unfavourable</td>
<td>62,7</td>
<td>57</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Improvement percentages of the new Machine.

During this checking process the improvement percentage goes through a sharp rise most likely due to the fact that, while the cycle time of each test was enhanced, we also went from checking one piece at a time to checking simultaneously two pieces. We do not count on with this advantage in the “calibration” sensors type and therefore the improvement is not so remarkable, although the calibration cycle time has been significantly reduced.

To determine the saving costs involved in the testing and calibrating processes, we took into account the saturation that each type of sensor has on the machine: checking type sensors have a 25% rate and calibration type sensors have a 75% rate (Table 2). This data allows us to estimate the value of pieces/hour depending on the use of the machine and according to the process.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Test type</th>
<th>pcs/h</th>
<th>Average pcs/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old one</td>
<td>Calibration</td>
<td>36</td>
<td>101</td>
</tr>
<tr>
<td></td>
<td>Testing</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>New one</td>
<td>Calibration</td>
<td>57</td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>Testing</td>
<td>173</td>
<td></td>
</tr>
</tbody>
</table>

Value / hour to FAE = 14,62 € / h

<table>
<thead>
<tr>
<th></th>
<th>Value old machine</th>
<th>0,145 € / piece</th>
</tr>
</thead>
<tbody>
<tr>
<td>New machine</td>
<td>Value new machine</td>
<td>0,064 € / piece</td>
</tr>
<tr>
<td>Saving with the new process</td>
<td>0,081 € / piece</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Saving costs of the new process

We notice that the testing process currently used represents a cost of 0,145€/piece, and with the new process the value is cut down to 0,064€/piece. This gives us a reduction of more than half the current price of the process, saving 0,081€/piece.

4. Test bench design

In Figure 4 an overview of the final design of the test bench is displayed.

![Test bench](image1)

Figure 4. Test bench

The design of the test bench (Figure 4) comprises a work bench, the main control station, the thread control station, the pneumatic circuit, an electric panel and all the purchasing and standard components to provide an easy access both to its operation and the placement of the tools or the sensors themselves.

The following image (Figure 5) shows the main module of the machine, the control station, where the sensors will be placed for conducting the test.

![Control station](image2)

Figure 5. Control station
We notice that there are two holes on the top of the control station, what means that you can check two sensors at the same time, although only those of the testing type, since the calibration sensors require a worker’s intervention, who cannot operate with two sensors at once.

In the Figure 5, the locking plate is ajar, reproducing the position and the movement it will have when being opened. Above this locking plate we find the interchangeable tooling which enable the electrical contact with the sensors and read their change of action. Below the locking plate, the polycarbonate sheets protect the access to the inside while running the test. Inside these shields, we can appreciate two pneumatic cylinders and above them we find the exchangeable tightness devices, where the sensors will be placed. Those cylinders should act for raising the sensors once we lower the cover and doing the tightness needed for the testing of the pieces, without causing any leak in the system.

Also on the bottom part of the locking plate, we notice a black cylinder being used as a latch to secure the cover once it is lowered. To ensure that the latch is in a closed position, we could operate other pneumatic cylinder horizontally placed on the inside of the testing module, which will act for fixing the latch and preventing it from being opened while the test is in process.

The testing module has two safety sensors, one located right beneath the locking plate operating only when the cover is fully closed, and the other one attached to the latch, being triggereded only if it is placed in the correct closing position.

Once these two switches are activated the test could be started, but if one of the switchers or neither of them is actuated, the testing could never take place even if the start button is pressed by the operator.

To make sure that the module is loaded with any piece before starting the testing, two fiber optic sensors have been installed at each station.

The secondary module of the new test bench machine is the thread control station (Figure 6).

To carry out this verification process we have used a comparator, which can be partially seen in the lower part of the image (Figure 6). To adapt it to our needs, we have designed an austenite stainless steel cylinder which could not be removed from its fixed position. It will be embedded on the top of the base sheet to be secured to the work bench. At the top of this cylinder we find another martensitic stainless steel cyndrical disc, being used to positioning the magnets and placing the tooling on the top. These tooling are also a kind of disc, having a specific shape on the inside required by each sensor, to be placed inside the disc which carries the magnets. The latter have the function of catching and holding the sensor by pressing it down, auto-placing and keeping it on the desired position to avoid having a misleading reading of the comparator.

Once the piece is correctly placed, the operator can press the green button and the reading taken out from the verification process will be displayed on the computer’s screen.

This module is the first step to test the sensors, so if the reading is not correct, the control station cannot be activated until a new piece will be placed at the thread control station with a correct pressure switch.

The machine has been explained and detailed little by little according to its internal division, which is essentially based on its subsequent assembly and maintenance.

Due to the current regulations on the field, the machine must be registered with a codification; in this case and following the format set out by the company, the test bench has been codified with the number M-1151.

Once we have made the final design of the new test bench clear, both its appearance as well as its functioning, we should back up its final design by discussing the ergonomic approach of the machine, that is to say, the reason why it has a certain geometry, the distribution of spaces and the shields used according to the procedures and movements the operator will carry out when using it.

The machine was thought to be worked by a single operator, with a centred and sitting position at the work bench, having access to all the parts of the machine requiring a mechanical process as well as to all the cabinets and boxes where the tooling, devices and pieces could be stored and where the sensors can be classified as well.

There is enough room on the work bench for the operator to arrange the materials and to handle the sensors, both regarding testing and / or calibration processes, as well as the classification and the placement of these devices.

Both the visibility and the measurement of the screen where the information is displayed during the cycle (both the PC and the MENSOR data) were taken into account, so that the operator did not need to be in a bad position or make any move at all to look at them.

The noise caused by the multiplier has also been insulated trying to minimize it, since it works at more than 85dB exceeding the safety limit imposed on the regulations.

The new testing bench has been furnished with hinged drawers and a small cabinet. The drawers are designed to make it easier for the operator to set up the sensors to be
tested, providing more space to place the boxes too. One of the drawers has been purposed to keep or store the keyboard and the mouse without causing any trouble to the operator, once the machine is ready to be started.

The cabinet was aimed at storing all the tooling and items needed to operate the machine. The exchange of tools and pieces is a regular procedure and it should be performed in a quick and easy way: SMED (Single Minute Exchange of Die).

After having outlined the final design of the new test bench and its ergonomics, a structural study has been carried out using SolidWorks software, in order to prove that parts of the machine as important as the work bench or the closure plate are totally safe and will withstand the demanded efforts under any circumstances or condition.

![Figure 7. Deformation of the closure plate](image)

With the help of these structural calculations (Figure 7), we have been able to dimension the core elements of the new machine in the best possible way and to choose the most suitable material for its manufacturing.

The estimations previously mentioned consisted on checking the level of deformation (in mm) and the Von Mises stress (in N/mm² or MPa) the element under the requested force can suffer, always applying a security factor (n=2).

5. Budget

In the table below you can find the summary of the final Machine budget, divided in different parts depending on the cost of each one:

<table>
<thead>
<tr>
<th>COST FOR PARTS</th>
<th>Cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of mechanical elements</td>
<td>15,142,71</td>
</tr>
<tr>
<td>Cost of pneumatics elements</td>
<td>11,150,41</td>
</tr>
<tr>
<td>Cost of electric elements</td>
<td>1,616,63</td>
</tr>
<tr>
<td>Cost of programming</td>
<td>7,782,14</td>
</tr>
<tr>
<td>Cost of design</td>
<td>10,240,00</td>
</tr>
<tr>
<td>Total Project Cost</td>
<td>45,931,89</td>
</tr>
<tr>
<td>Supplement for unforeseen changes and additions</td>
<td>15%</td>
</tr>
<tr>
<td>TOTAL COST OF THE PROJECT</td>
<td>52,821,67 €</td>
</tr>
</tbody>
</table>

Table 3. Budget summary

The budget for the machine has been divided into different sections, for record purposes, to show every cost of the test bench, from the purchased components and the manufactured parts, to the assemblies and sub-assemblies, the mounting or the designing and assembly hours spend on the machine.

The estimated expenses have been conducted according to the company profile and they are divided into three major sections.

In the first section we provide a diagram of the machine detailing the main and secondary features of the project, the estimated capacity production, the final cost of the machine together with the amortization, and a brief description of other elements and aspects to take into consideration.

This first scheme is the one being presented to the different departments in the company (Finance and Accounting, Marketing, Sales and Managing) so they could have an overview (non-technical) of the machine structure, as well as the manufacturing and amortization total balance.

To determine the amortization cost of the machine, first we had to find out the annual manufacturing capacity of the mechanism, in order to verify if it will suit the budgetary forecasts:

<table>
<thead>
<tr>
<th>Estimated cost of the system</th>
<th>pcs/hour</th>
<th>(with saturation)</th>
<th>pcs/any</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of test ‘calibration’ (saturation 75%)</td>
<td>76</td>
<td>57</td>
<td>99,750</td>
</tr>
<tr>
<td>Type of test ‘checking’ (saturation 25%)</td>
<td>693</td>
<td>173</td>
<td>303,188</td>
</tr>
</tbody>
</table>

TOTAL PIECES YEAR 402,938

Table 4. Estimation of capacity

We know that the expected number of sensors to be produced in the coming years amounts up to 300,000 pieces, so the machine has proved to be fully capable of manufacturing these quantities without any doubt.

We are also acquainted with the total cost of the new machine, the savings we will get per piece and the annual manufacturing forecast to comply with:

- Total cost of the new machine = 52,822 €
- Saving = 0,081 €/piece
- Forecast of annual manufacturing = 300,000 pcs/year

Now calculate amortization (in years):

Amortization = 52,822/0,081/300,000 = 2,2 years

In this way, we are completely sure the machine will be fully amortized in a two-and-a-half years’ time. Due to such a short depreciation period, the company has considered the manufacturing of the machine as a feasible project.

The second part of the budget is also an overall description, more detailed than the previous one, describing the cost of the machine according to its technical components (mechanical, tires, electrical, programming and designing cost), as well as the total balance of the machine. In each of these sections the cost of every component the machine is made up has been detailed, whether being manufactured or purchased on the market, including the assembly hours and the final cost of the project.

The third and last part of the estimated expenses can be found on the attachment documents at the end of the
6. Drawings

All the drawings that put together the machine are easy to access, as they are attached at the end of the project and they have been placed in order according to their codification. In the same section you can find also the pneumatic and electrical diagrams for assembling the machine (bear in mind that the electrics are out of the scope of the project).

The drawings are arranged so that the first ones are the generic diagrams, finishing with the drawings that made up the machine.

7. Specifications

The specifications part outline the general legal provisions of the project and the technical conditions of the machine materials.

It is a document that should be attached to the test bench and it must be complied with in order to obtain the CE mark the machine needs to be manufactured and used.

It is important to note that the machine has been designed to be the only one unit built for the proper use of the company.

The first section of this paper provides a description of all the components of the machine, as well as the sub-groups or assemblies that put it together. It also details all the safety elements used for the setting up of the machine, including their location, their function and a brief explanation of the appropriate use of these security systems. This part of the document contains as well a definition of the specific operations the machine has been designed for and a brief section with the contra-indications the mechanism may have if being misused.

In the general description of the machine, the workplace and the specific number of operators needed for the functioning of the mechanism is also detailed, as well as all the automatic processes of the machine.

In the last heading of this section, the maintenance of the machine is mentioned, both the preventive and the corrective, necessary for the smooth functioning and the useful life of the machine.

The environmental requirements to the suppliers of the materials, either direct or indirect, are also included in this section, with a detailed description of the regulations that have been taken into account during the design and assembly of the machine, including the security records and the safety data sheets of the materials used to make up the mechanism.

Another section included in the specifications part deals with the safety of the machinery. It contains all the documents related to the CE mark and the plate with the same labelling, which must have the following information on it:

- Name: TEST BENCH FOR PRESSURE SWITCH
- Brand: FAE
- Model: ---
- Serial N°: ---
- Year of production: 2015

The CE mark ensures that the machine meets all safety standards and it has been certified for its use within the European Union.

The IG Machine (instruction book of the machine) is also attached to the mechanism, where the safety elements and the limitations regarding the handling of these elements are clearly explained.

As our machine has some components exceeding the acoustic limits allowed by the regulations (the multiplier), the measures that have been taken to minimize the noise levels must be detailed in this section, as well as account for the levels obtained with the applied improvements.

- Acoustic pressure level weighted equivalent continuous A (LpAeq): 80 db
- Acoustic pressure level weighted instantaneous C (maximum value) (Lpc): 95 db

The ergonomics of the machine have been also included in this part of the document, displaying the regulations that have been complied with to turn the test bench into a practical and comfortable work place, both safe and ergonomic, as well as the reports made by the subcontracted external company that has certified the machine as suitable for its use.

Finally, other relevant information has been attached to this last section, detailing all the documents the machine must take into account to be used:

- Set of drawings of the machine with all the necessary views for proper interpretation
- Set of drawings of the toolings and components for easy replacement.
- List of the purchased components used and their quantities
- List of the safety elements, their quantities and their positioning in the mechanism.
- Pneumatic and Electrical diagrams
- CE marking certificate
- IG of the machine (instructions book of the mechanism)
- Operation Manual according to current regulations.
- Maintenance Plan of the machine
- Instructions for handling and disassembly the machine
- Potentially Dangerous Items
- Signalling and supplying of the PPE

In the document dealing with the maintenance of the machine, mentioned in the listing above, two different preservation proceedings are described. The preventive plan of maintenance Level 1 will be carried out by the operator
who will be using the machine, and the preventive plan of maintenance Level 2 will be performed by the certified technicians. This document will consist of a summary of all the operations carried out by the machine, the frequency with which they occur, the methodology used in each situation, etc. as well as a brief section left for further improvements on the machine.

As far as warranty is concerned, and as it has been already mentioned, the machine will not provide any guarantees to third parties, due to its private use for the company only, although it must count on with a document mentioning all the purchased components, which have to offer a guarantee of proper functioning.

8. Conclusions

We could design a simple and effective test bench to check and regulate the pressure switches (it has been added other types).

As demonstrated before, the machine meets all the objectives and requirements of the production department and others that participated in the brainstorming. It is capable of checking and regulating while detecting parts OK or not OK, check that the height of the thread is correct and perform a leak test (although the devices do not use leak testers).

The cycle time and the lack of precision have been improved exponentially. Human error has been reduced to the maximum and the new test bench would be able to collect production data and research, store it in a database that can be used to study these values.

It has also been demonstrated that the process is not only faster than the current machine, it is also cheaper, enabling rapid amortization.

The improvements proposed by the different departments have been carried out at 100%, keeping the strengths of the current machine.

The new test bench meets all the regulations and is a safe and ergonomic machine. This makes it possible to have a simple design, intuitive for the operator, also making it a machine that can evolve, change and easily adapt to new designs.

Personally I have achieved new knowledge in areas such as industrial pneumatics, hydraulics, machine safety, electricity and especially in designing.

It was not an easy project, I devoted a lot, and there are many hours of work, as it has been necessary training courses, about machine safety or hydraulics to carry out the development of this design.

9. Acknowledgments

I mainly thank the company Francisco Albero SAU (FAE) for giving me this opportunity and trust me to design a machine like this, especially my boss David Requena and my colleagues in the engineering department. I also want to mention their great involvement and the possibility they offered to receive training in courses about Security or Hydraulics, in such an important company as it is FESTO.

I also thank my family and my partner, especially my mother for correcting me and give me her support while writing and rehearsals. Of course, I also thank both companies for their help in correcting my English translation of this project.

Finally, I want to mention my tutor, Montserrat Carbonell, for the dedication and commitment when she gave me advice as it is not easy to manage and edit a project commissioned by another company or organization.

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