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Automation of the torque process in the assembly of the component called Frontcover as an integral part of an internal combustion engine.

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Abstract

Automate the assembly process of the front cover of the internal combustion engine to have a focus on reducing the process cycle time, control the rejection of NG parts, maintain the quality of torque applied to each screw of the assembly and have a flexible system for the assembly of different models, applied research to the process of assembling the front cover of the internal combustion engine is presented. Under this scheme, it is necessary to assemble 1600 motors per day at maximum capacity and reduce from 8% of parts that currently come out as a rejection to 2%, taking into account that the objective is to have an efficiency of 98% of the process, so it is intended to implement a team capable of applying and controlling the torque automatically to each of the screws of the assembly with assembly capacity for the 3 models Available. To implement this equipment, it was necessary to analyze the current assembly process that is had, as well as the work area where the equipment was installed, also the types of screws that were used for the assembly and the torques applied to each of them. Taking into account these conditions and under a series of tests and analyses, it was determined which devices would be used for the integration of the equipment, as well as the design of the tooling for the dice that came into contact with the screws for the application of torque.

Keywords: *Automate, integrate, flexible system, cycle time.*

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1. Introduction

Within a company you have the assembly of an internal combustion engine, in which each process is adapted each component that makes up the engine, from the adaptation of the structure to final tests that indicate the good performance of the complete assembly of the engine. One of the processes where you have a bottleneck in production times and some details of the final quality of the assembly of the front cover of the internal combustion engine. This process is performed manually by means of a pneumatic gun that would be operated by a person, taking into account each torque in a sequential way as explained by its standard operating sheet for that process., the format sheet consists of explaining to the operator by means of animations and steps the correct use of the torque application device, as well as the torque sequence in each of the screws that are inside the assembly of the front cover of the engine. This process does not show indicators or records of torque data in the screws of the assembly of the front cover, in addition to not having a poka-yoke system which respects the specific sequence of torque in the screws in such a way that the probability of an error derived from the human factor is presented is considerably increased when performing the activity. As part of the observation of the problem arises the need and interest to make use of the application of technologies and innovation for the improvement of the process, which, thanks to the tools acquired during the postgraduate process, the automation of the same can be carried out, it is also important to mention the support provided by the company to develop the present work, which I present another reason for inspiration to proceed with the development of this improvement.

It is necessary to improve the application of torque in the assembly of the front cover in order to have a more autonomous process and reduce times in the process of the application of torque and thus be able to minimize rework costs, reduce the cost of the product, lower the percentage of rejection and rework material caused by a potential operation error. Automating this process will have as its main beneficiary the assembly line, it will also generate a benefit in the quality of the application of torque in the assembly of the frontcover component, and finally it will have a positive impact economically by being able to reduce the number of reworks made due to rejection of assemblies by this process.

For the development of this project, some objectives were taken into account such as 1) designing and developing the electrical system of the devices that will integrate the process, as well as the design of the operation panel and the electrical panel of the equipment in the SolidWorks electrical platform, 2) perform the Integration of the electrical board and both external and internal components thereof, 3) perform the process flow diagram for application in GRAFCET that will serve as the basis for the programming of the equipment, 4) program the interface for handling the equipment, as well as the sequence in the PLC, 5) Trace the sequence of movements of the Cartesian robots of the IAI brand for the application of torque by means of coordinates to the different specific points of the screws of the cover, 6) integrate a special system of application of torque and angle for the application of the equipment of the SANYO brand, which allows in a friendly way the configuration of parameters for different torque applications, 7) perform a statistical analysis to compare the data of the torque equipment of each screw with the expected results for quality, 8) send the torque data to the traceability system from the PLC to a computer to have the record of each assembly that passed through the equipment and 9) reduce the times and costs of the process by optimizing the process sequence. For this research the PDCA cycle and also known as the Deming cycle was used [1], which is used by some companies looking to improve their quality standards and operate more efficiently. A cycle consists of four phases of planning, doing, verifying and acting. For that reason, it is also known by the acronym PDCA in English [2]. An example of its application is show in Fig. 1.

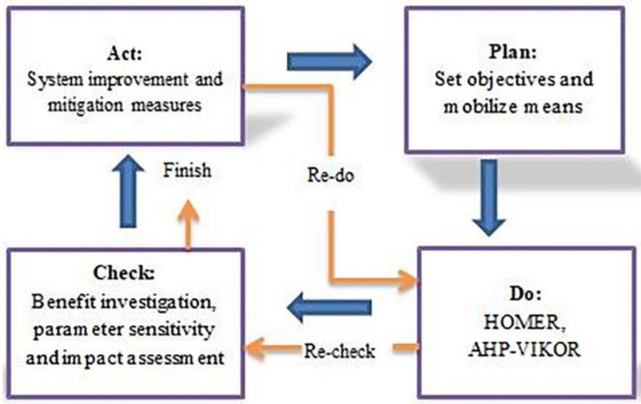

Fig. 1 Example of the application of the PDCA cycle [2]

The hypothesis of the project:

H1. Is possible to improve the repeatability of torque application in the frontcover cover screws by decreasing material rejection by sequencing and programming each torque point with the help of a Cartesian robot and the applied torque control system.

H2. Is possible to integrate the torque data traceability system applied to the screws by capturing data from each screw section of the frontcover cover by sending it from the PLC by using a MES IT interface connected to an ethernet network to a computer using data storage software.

H3. Is possible to reduce costs and have a higher speed in the torque process in frontcover by coordinating the axes of the robot by teaching it the shortest routes of torque application at the different points of the screws within the coordinate system versus, the process that is currently used which is the assembly manually.

2. Methodology

The PDCA cycle was used in this work to strengthen coherence between planning and the actual project, as well as for the continuous improvement of the planning process. The uniqueness of this model is the feature of supporting the management of the PDCA cycle that provides coherence between the planning process and the actual project, as well as criticisms and responses for the proposed system [3]. The results of the implementation of the PDCA method can be used to solve the qualitative and quantitative data problems that have been widely applied in the service and manufacturing sectors for continuous improvement and as a working pattern in improving a process or system in an organization and increasing productivity [4].

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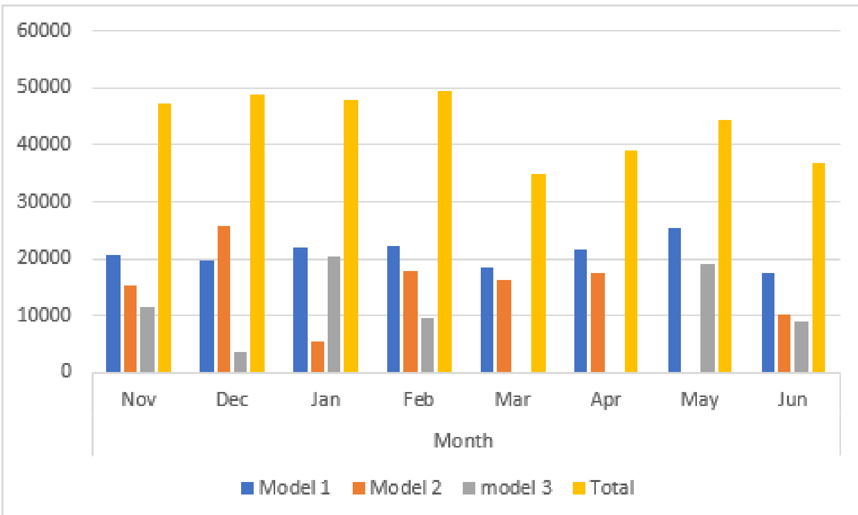
The methodology to be followed was based on the application of the PDCA cycle as previously mentioned, this method consists of applying four phases, which are, 1) Plan, 2) Do, 3) Verify and 4) Act [5]. The following subsections to describe how each phase of PDCA was applied in this project.

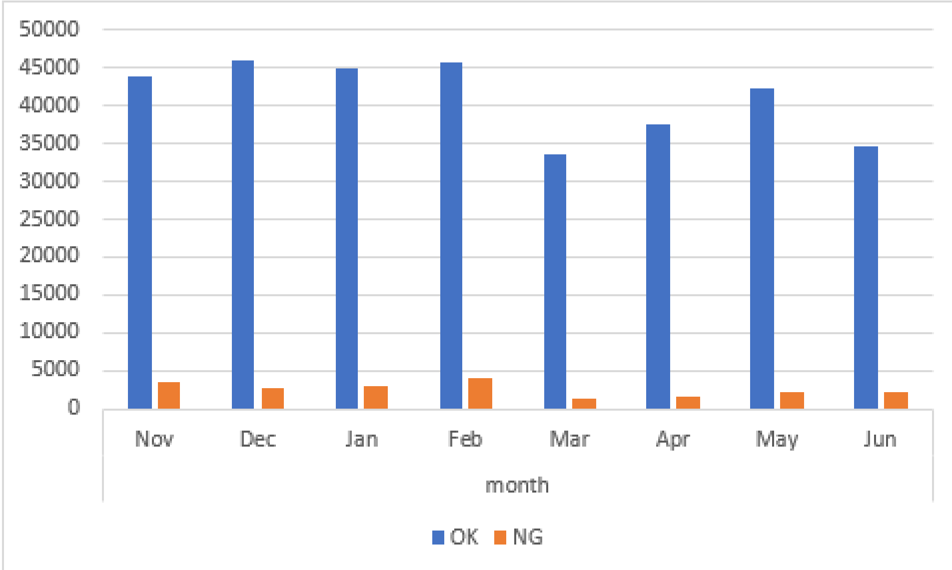
2.1 Phase 1: Plan

It means planning to have a goal (GOAL = OBJECTIVE) and what process is needed to determine the results that are synchronous with the specifications of the objectives set [6]. In this phase the current situation of the assembly process of the front cover of the internal combustion engine is verified, information is collected on the data of OK and NG parts that is currently available in the assembly line shown in fig. 2 and fig. 3 and the flow diagram of the methodology to be applied shown in fig. 4 is made. To find a solution you need to apply root cause analysis (RCA) asking the 5 questions Why? to determine the problem and thus be able to develop the flowchart of the assembly process to be implemented as shown in Table 1. RCA is the process of deducing and understanding the underlying cause of the current need [7].



	Month							
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Model 1	20600	19670	22000	22105	18600	21640	25400	17640
Model 2	15280	25600	5400	17860	16300	17460	0	10100
model 3	11500	3480	20500	9635	0	0	19000	8950
Total	47380	48750	47900	49600	34900	39100	44400	36690

Fig. 2 Total parts assembled in the line during the year 2020-2021



	month							
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
OK	43921	45971	45026	45632	33504	37536	42180	34488
NG	3459	2779	2874	3968	1396	1564	2220	2202

Fig. 3 OK/NG parts assembled in the line during the year 2020-2021

Problem	Why?	Why?	Why?	Why?	Why?
The assembly line does not have an efficiency of 98%	assembly line generates many NG parts	Failures are made when applying torque	parts are assembled manually by the operator	the indicators and sequence of applied torque are not displayed on any screen	the assembly line does not have an automatic system for torque application
Goals	Root cause				
have an automatic system	the assembly line does not have an automatic system for torque application				
reduce the number of NG assemblies generated					
Increase the production speed					
reduce the cost					
Countermeasure					
Installation of a system with the capacity to perform the operation automatically, the system must have control in the application of torque in the screws and this generates indicators of the sequence and data collection					

Table 1 Phase 1. Identification of RCA, using the five-cause methodology

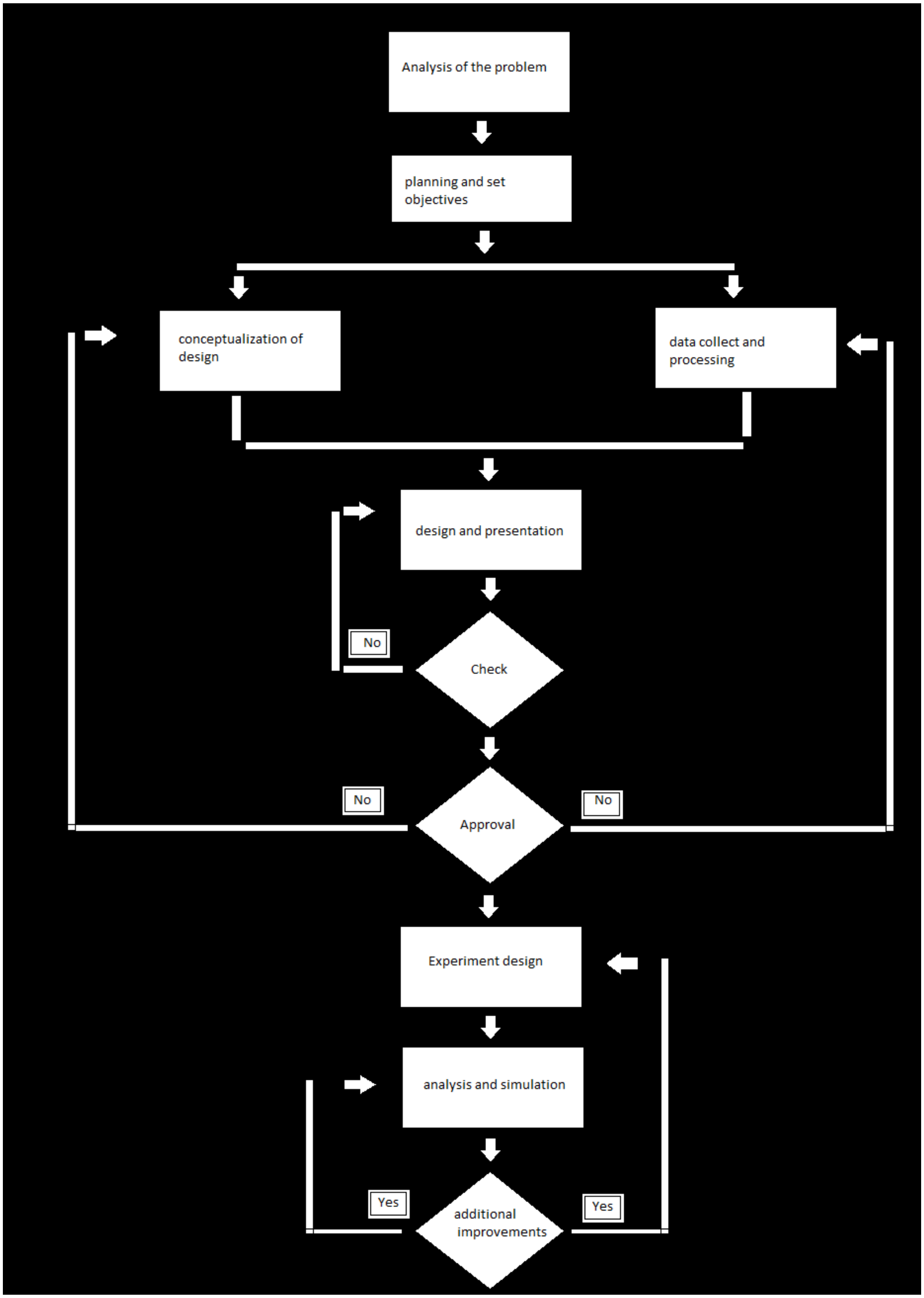


Fig. 4 Stages of the simulation applied for this project.

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2.2 Phase 2: Do

Do the planning of the process that has been previously determined. The measures of this process have also been determined at the plan stage. It generally requires testing and adjustments until an effective and simple to maintain implementation is achieved [8]. It is in this phase where the strategies considered because of the questions posed are applied and that are aimed at implementing a new equipment subject to improvements depending on the analysis carried out in the following phases. Table 2 shows the organization of the staff to carry out this project.

Goal	Implementation for Countermeasure		
	task	responsible	deadline
implement of new machine for applied torque in the screws	Mechanical Design	Enginering department	7/25/2021
	Structure design	Enginering department	8/15/2021
	Pneumatic and hydraulic design	Enginering department	8/15/2021
	Electrical design	F. Duran	9/10/2021
	Tool design	F. Duran	9/10/2021
	Mechanical & structure manufacturing	Manufacture department	10/20/2021
	Programming machine	F.Duran	11/28/2021
	Installation	Multi.team	12/20/2021
	Start up	Multi.team	1/2/2022

Table 2 Phase 2. The order of the activities to be implemented by a multidisciplinary group and with a focus on the implementation of the machine is systematically presented.

For the implementation of the equipment, those taken into account in the information collected in fig. 2 and fig. 3 were taken into account, with that information plus the data taken by the RCA analysis, the necessary specifications were made for the design and manufacture of the machine to be implemented.

An important point to consider are the torque specifications applied to each of the screws shown in Table 3 and the sequence that the robot will take to move in each position of the screws using a coordinate system as can be seen in Fig. 5.

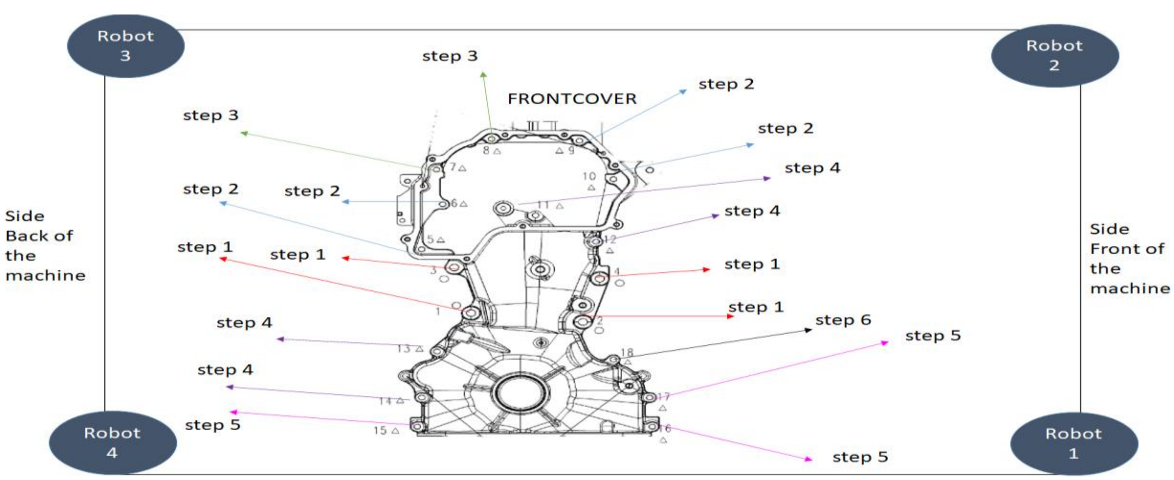


Fig. 5 Robot secuence movements for torque aplication in the screw.

STEPS	ROBOT	TORQUE
1	1,2,3 & 4	43-55N
2	2 & 3	11.8-13.7N
3	3	11.8-13.7N
4	2 & 4	11.8-13.7N
5	1 & 4	11.8-13.7N
6	1	11.8-13.7N

Table 3 Sequence torque application

With the information obtained, the design of the tools and the structure of the machine was carried out with the help of the SolidWorks design software as shown in fig. 6 and fig. 7., the finite element analysis was also performed to see the resistance of the material of the tooling by the support of the ANSYS software as shown in fig. 8.

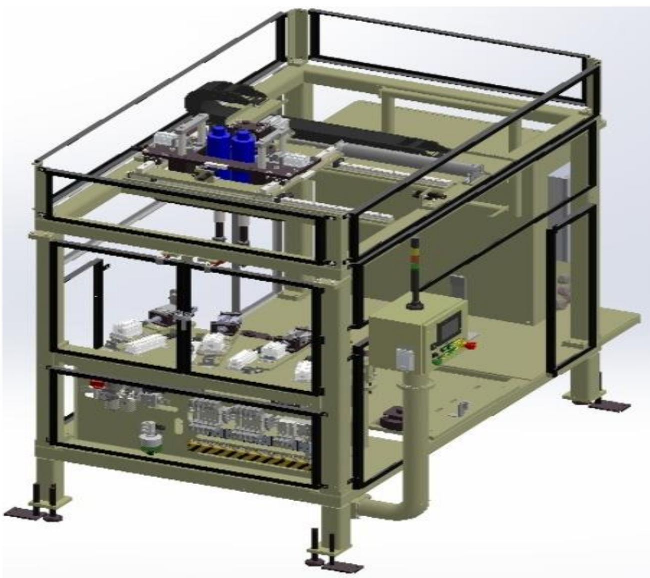


Fig. 6 Machine Structure .

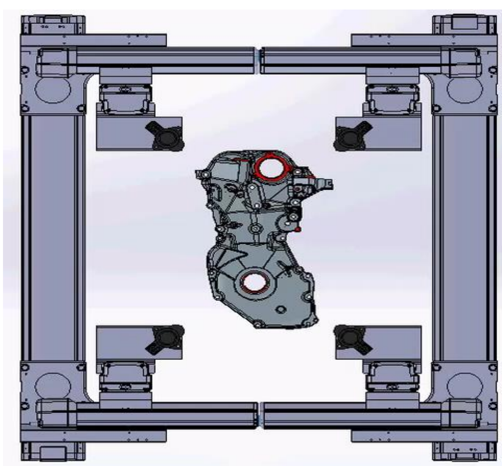


Fig. 7 Robot Structure .

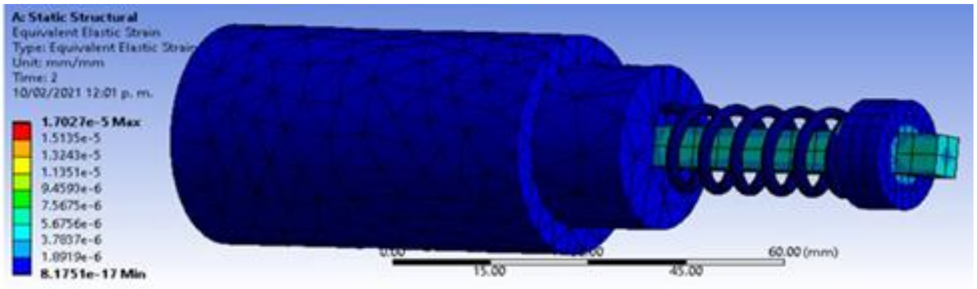


Fig. 8 Analysis of the finite element of the tooling .

By having the approved design of the tooling and the structure of the machine, the pneumatic, mechanical and electrical design that the equipment would need for its functionality was carried out, as well as the manufacture of the equipment as shown in fig. 9, 10, 11 and 12.

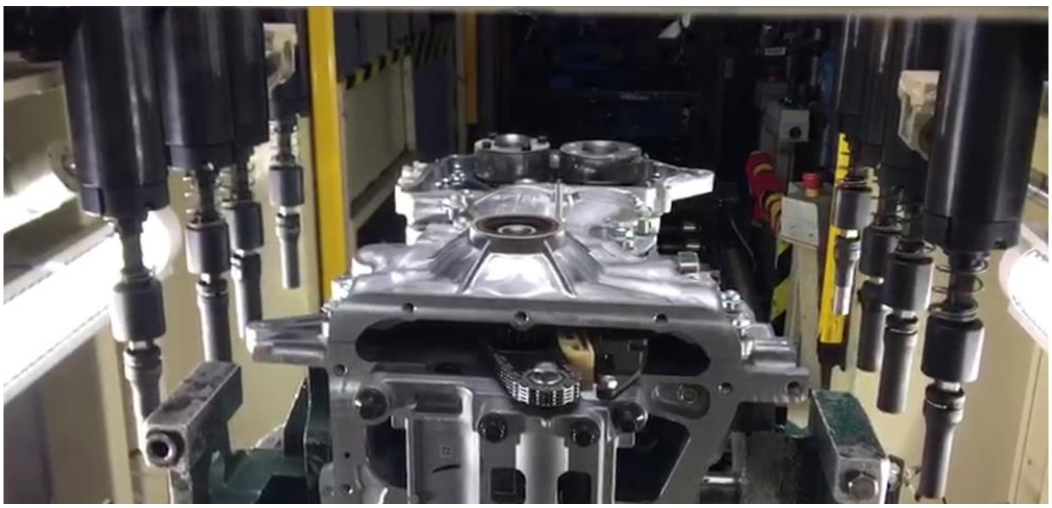


Fig. 9 tooling .

Fig. 10 Robot structure.

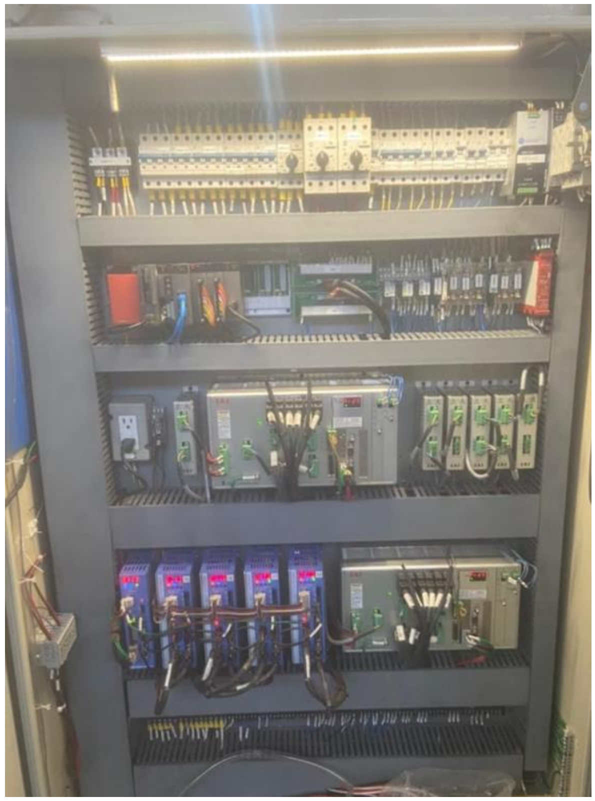


Fig. 11 Electrical cabinet.

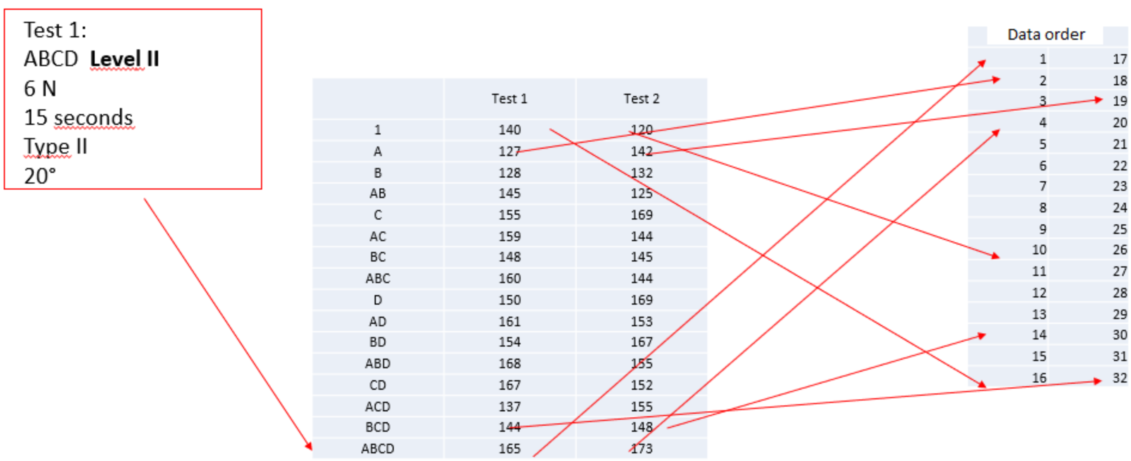
Fig. 12 structure machine.

2.3 Phase 3: Check

The objectives and processes are evaluated to inform the results obtained, all this through an ANOVA data analysis, a Duncan test and a scatter plot to see the best option and if the hypothesis is true for the implementation of the machine. The data to be taken into account in the torque application are shown in Table 4.

	Factor	Level 1	Level 2
A	Pre torque	1N	6N
B	Torque time	10 sec	15 sec
C	Tooling	Type 1	Type 2
D	Torque Angle	15 grades	20 grades

Table 4 Data Test



	Test 1	Test 2
1	140	120
A	127	142
B	128	132
AB	145	125
C	155	169
AC	159	144
BC	148	145
ABC	160	144
D	150	169
AD	161	153
BD	154	167
ABD	168	155
CD	167	152
ACD	137	155
BCD	144	148
ABCD	165	173

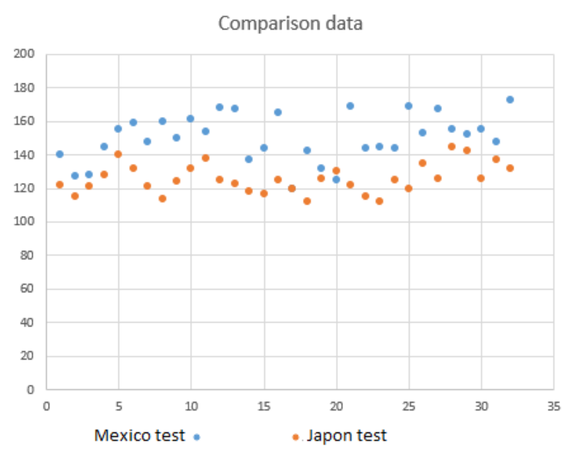
Data order	
1	17
2	18
3	19
4	20
5	21
6	22
7	23
8	24
9	25
10	26
11	27
12	28
13	29
14	30
15	31
16	32

Fig. 9 Collect data torque after angle aplication radomly for the test .

Once the data has been acquired by performing random tests by means of a sampling, the comparison of the data is made against another equipment installed in Japan as shown in fig. 10.

New machine test

test	
140	120
127	142
128	132
145	125
155	169
159	144
148	145
160	144
150	169
161	153
154	167
168	155
167	152
137	155
144	148
165	173



Japon test

test	
122	120
115	112
121	126
128	130
140	122
132	115
121	112
114	125
124	120
132	135
138	126
125	145
123	142
118	126
117	137
125	132

Fig. 10 Comparison data between both machines.

2.4 Phase 4: Act

When performing the graph, it can be observed that the torque applied after angle application rises more compared to the comparative equipment installed in Japan, therefore, a design of experiments is carried out applying an ANOVA test and a Duncan test to make a total evaluation of the results of the objective and the process by following up through improvements. If there are still deficiencies in the process, a corrective action will be taken immediately., in fig. 11 and fig. 12 the result of the test is shown.

EFECT	SS	GL	MS	FO	FT	HYPOTHESIS NULL
SSA	19.5	1	19.53	0.20038474	4.49	TRUE
SSB	0.0	1	0.03	0.00032062	4.49	TRUE
SSAB	399.0	1	399.03	4.09394037	4.49	TRUE
SSC	520.0	1	520.03	5.3353639	4.49	FALSE
SSAC	1.5	1	1.53	0.01571016	4.49	TRUE
SSBC	16.5	1	16.53	0.16960564	4.49	TRUE
SSABC	294.0	1	294.03	3.01667201	4.49	TRUE
SSD	1725.8	1	1725.78	17.7059955	4.49	FALSE
SSAD	1.5	1	1.53	0.01571016	4.49	TRUE
SSBD	108.8	1	108.78	1.11606284	4.49	TRUE
SSABD	69.0	1	69.03	0.70823982	4.49	TRUE
SSCD	1262.5	1	1262.53	12.9531901	4.49	FALSE
SSACD	81.3	1	81.28	0.83392113	4.49	TRUE
SSBCD	47.5	1	47.53	0.4876563	4.49	TRUE
SSABCD	38.3	1	38.28	0.39275409	4.49	TRUE
SSE	1559.50	16	97.47			
SST	6144.96875	31				

CONCLUSION
NULL HYPOTHESIS IS REJECTED IN C,D AND CD THEREFORE DUNCAN TEST IS PERFORMED.

Fig. 11 ANOVA test.

	Test 1	Test 2					
1	140	120					
A	127	142		1	C	D	CD
B	128	132		140	155	150	167
AB	145	125		120	169	169	152
C	155	169		127	159	161	137
AC	159	144		142	144	153	155
BC	148	145		128	148	154	144
ABC	160	144		132	145	167	148
D	150	169		145	160	168	165
AD	161	153		125	144	155	173
BD	154	167		132.375	153	159.625	155.125
ABD	168	155					
CD	167	152			lowest to highest		
ACD	137	155		1	C	CD	D
BCD	144	148		132.375	153	155.125	159.625
ABCD	165	173					

Fig. 12 DUNCAN test.

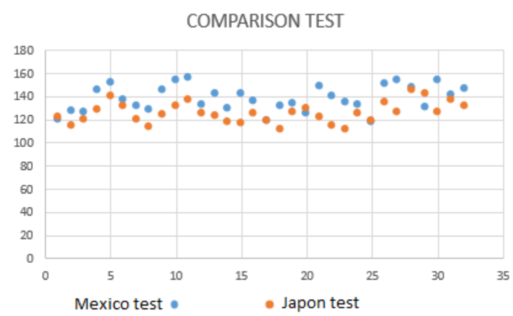
In order to have an optimal configuration for the torque of the frontcover to the engine it is necessary to take into account the following configuration:
Initial pre torque of 6 N, torque time of 10 seconds, use the Type I tooling, apply a torque angle of 15°.

3. Analysis of results

When performing both tests and having the optimal configuration for the equipment, random tests were carried out to compare once again the data obtained against the expected data, in fig. 13 the data are shown.

NEW MACHINE

TORQUE TEST	
121	120
127	132
126	134
145	125
152	149
138	140
132	135
129	133
145	118
155	151
157	154
133	148
142	131
130	154
142	141
136	146



JAPON MACHINE

TORQUE TEST	
122	120
115	112
121	126
128	130
140	122
132	115
121	112
114	125
124	120
132	135
138	126
125	145
123	142
118	126
117	137
125	132

Fig. 13 Comparison data between both machines after experiment design.

By having greater control over the data as shown in the figure above, the equipment is put in place to monitor the data and see if the reduction of NG material falls below e3star within the expected range, in fig. 14 the data are shown.

	2022	
	Jan	Feb
OK	44333	38212
NG	350	240

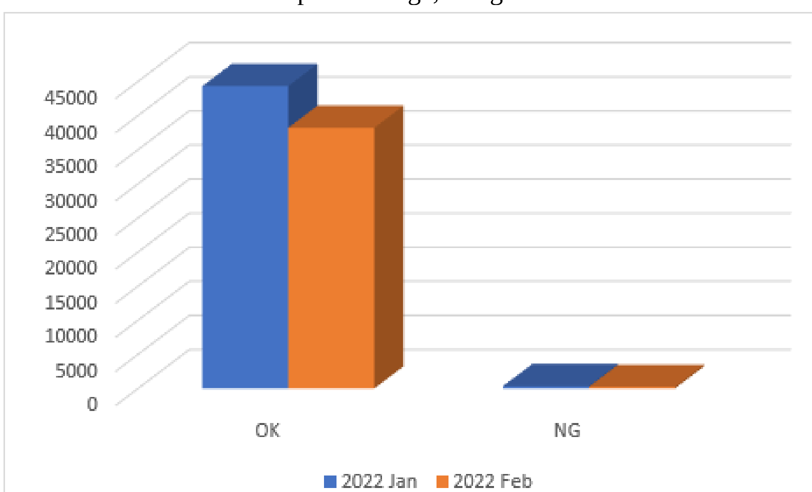


Fig. 14 OK/NG parts assembled in the line during the year 2022

4. Conclusions

The hypothesis proposed in the first stage of the PDCA was satisfactorily fulfilled since with the changes implemented the machine is able to automatically perform the assembly process, it also has greater control in the quality of torque application in the screws, it is also fulfilled when visualizing in the table a reduction of NG material, having a higher efficiency of 98% as expected.

It was also shown that the use of the Deming cycle or better known as PDCA and the application of the design of experiments remains an effective tool for the development of continuous improvement.

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