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IMPLEMENTATION OF DESIGN IMPROVEMENT IN A LCD MONITOR PRODUCT THROUGH THE APPLICATION OF FUZZY LOGIC AND QUALITY

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ABSTRACT

Companies all over the world aim to launch a considerable amount of new products every year. During this process, project failures and design problems are often detected. In this context, this paper aims to scientifically explore the events that occurred during the implementation of a new LCD (Liquid Crystal Display) monitor product, where its functionality, appearance, quality, and cost are considered satisfactory; however, its design has a negative impact on the mass production process and presents a great need for improvement. The study then sought to understand the causes of the problem and apply some solutions, especially for the biggest defect found in the project: infiltration of adhesive inside the joystick button actuation mechanism. The applied methodology used quality tools (PDCA, Ishikawa and Kaizen) and parameters from Fuzzy logic tools (linguistic variables, fuzzyfication, Inference rules and defuzzification). As a final result, the organization obtained several benefits, such as reducing the defect rate from 20% to 3%, reducing costs with spare parts and repair service, and increasing quality and productivity indicators.

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INTRODUCTION

The current world has increasingly demanded that companies continuously innovate and improve their products through the increase of technological resources (CHAPMAN *et al*, 2002). Throughout the world scenario, these organizations undergo constant changes and many of them are related to the increase of competitiveness and, in some cases, for reasons of survival (FREITAS & MERINO, 2016). Such results are achieved with continuous investments in innovation and improvements in their products and/or processes. Morgan (2008) makes it clear that this systematic also requires a high level of quality allied to the reduction of operating costs. Pereira *et al* (2009), Kalleberg & Leicht (1991) emphasize that the quality of a service or product are the main factors responsible for the survival and success of a particular business in the market, where corporations are increasingly engaged in the search for qualification for their employees as well as improvement of machinery and equipment. Because of this, the engineering involved has a fundamental role in guiding this process. In this context, one must think of engineering as a whole, from product design, its development process, testing, and mass production. It is not enough for a product to have good functionality and appearance, if its assembly operation is complex, slow and unstable. It is necessary to plan how it will be produced in large scale, its assemblability, the amount of connections involved, quality problems, ergonomic issues and production costs (DAUZÈRE-PÉRÈS *et al*, 2002). Veríssimo *et al* (2003) and Rennels (1984) agree that nowadays, tolerating process defects because of design problems has become inconceivable. Even if there is a financial margin, it is essential that the company prioritizes the process and continuous improvement of quality with a view to optimizing the design of products through the application of quality tools to obtain more reliable products that provide greater financial gains. In view of this, it is noted, in recent decades, the emergence of several quality tools, with the aim of ensuring the manufacture of products and/or provision of services with low rates of defects (SHARMA, 2013). In this sense, the PDCA cycle created in 1930 by Walter Shewhart and popularized in the 1950s by William Edwards Deming, served as a basis for the application of design improvements and also in the manufacturing process referred to in this case study (BEST & NEUHAUSER, 2006). Another tool used for product and process design improvement in this case study was the Cause and Effect Diagram, or Ishikawa Diagram. This tool has generated significant advances in improving product and process quality in companies (BIALY & RUZBARSKY, 2018). Considering that the problem-solving process is one of the pillars of Quality Management, the Ishikawa Diagram made it accessible and simple to use a powerful cause analysis tool that could be used by non-experts in the field (CARD, 2013). According to Gupta (2006), Ishikawa and Deming used this diagram as one of the first tools in the quality management process. The current scenario of growing importance of quality in all sectors favors the need for this type of study, not only in industries and manufacturing companies, but also in the service sector. After all, satisfying the consumer's needs has become one of the central objectives of organizations and a means of evaluating their overall performance, according to (MARCHETTI and PRADO, 2001). Finally, one way to know if a company is fulfilling its mission is to systematically measure its quality and productivity indicators, analyzing failures, developing lessons learned, reducing costs and continuously seeking ways to improve their products and services (CAI, 2009).

REVIEW OF LITERATURE

According to Slack *et al.* (2009), production management is the activity of managing resources for the production and availability of goods and services. Chiavenato (1991) complements this by saying that each company adopts a production system to perform its operations and produce its products or services in the best possible way, and thus ensure its efficiency and effectiveness. In order to achieve this, Rozenfeld *et al.* (2006) states that, based on market needs and technological possibilities and restrictions, it is necessary to arrive at the design specifications of a product and its production process, so that manufacturing is able to produce it. In organizations, the production process is the transformation of inputs, that is, raw materials, technology, financial and intellectual capital, among others, into outputs, which can be products and/or services (GAITHER; FRAZIER, 2006). In this context, it is important to have a quality system that guides the process of introducing new products. For this, the PDCA is considered a great way to achieve the goals assigned to the products of business systems (CAMPOS, 2014).

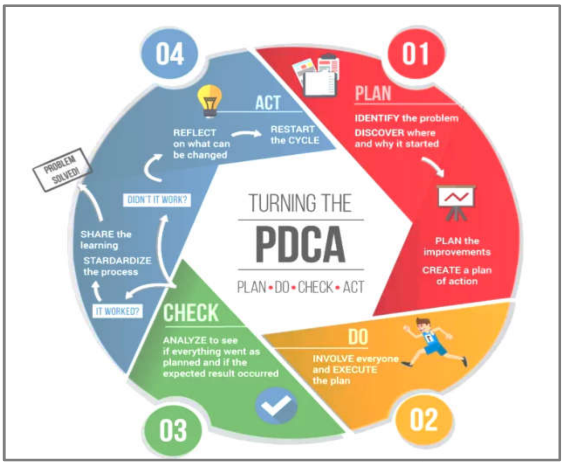


Figure 1. PDCA Cycle. Source: Siteware, (2021)

Corrêa and Corrêa (2011) summarize production management as being the activity of strategic management of scarce resources, their interaction and the processes that produce and deliver goods and services aiming to meet needs and/or desires of quality, time and cost of their customers. Romeiro (2004) complements this concept by saying that the elaboration of technical specifications from the identification of the consumer market needs is essential to have a strict quality control during product development. According to Miguel (2006), quality tools are often used as a support for quality development or as a decision support in the analysis of a certain problem. The Cause and Effect Diagram or Fishbone or Ishikawa Diagram was first applied in 1953 in Japan by Kaoru Ishikawa, in order to synthesize the opinions of engineers when they discussed quality problems (PEREIRA, 2014). Mata-Lima (2007) states that application of the tools to identify the cause of problems requires that there is a debate among the stakeholders. According to Souza (2013), the application of the Kaizen tool in organizations began soon after the Second World War in Japan. At that time the country was going through a difficult situation, since it had lost the war and its companies needed to grow, but there was no capital to be invested and there was no possibility of incentive from the government. In Wolfinbarger and Gilly's (2003) findings, two dimensions of quality (design and fulfillment) were predictors of satisfaction. Design quality had positive association with loyalty, satisfaction, word-of-mouth, and not significant with value. The result of the design quality-satisfaction relationship was the same as Szymanski and Hise (2000), indicating that design is a potential explainer of satisfaction in electronic environment. Kaizen means the continuous improvement of a complete value stream or an individual process in order to add more value with less waste (ARAUJO, 2006). Sharma (2003) contributes by saying that the Japanese characters of the word Kaizen mean. Do Well (KA = change; ZEN = well). Regarding process design, Villela (2000) summarizes that this concept consists in designing new processes and transforming business processes. These are analytical, creative, visual and logical description activities of the process steps and the way work is organized. Mariano (2012) contributes by saying that process design is a step that occurs after the analysis and discovery steps. Its goal is to create an improved and optimized version that meets all process performance expectations and strategic business needs. There are techniques for finding the best design. These tools are listed in the CBOK (CBOK, 2013):

- Goals and objectives
- Performance
- Workflow
- Platforms and technologies
- Data source
- Operational and financial controls
- Integration with other processes

SURVEY METHODOLOGY

The proposed methodology was developed as action research, which meant in active role in analyzing the problem and developing solutions within the research environment (KOERICH, 2009). In general, the investigation adopted an analytical procedure through personal observations and data survey, based on the PDCA methodology, with application of other quality tools during the whole process.

Materials

- Mitutoyo digital caliper, 0.01 mm resolution;
- Digital dynamometer;
- Digital microscope;
- Software associated with the digital microscope
- Microcomputer with Windows 10.

Method

- Separate 100 samples of keys mounted on printed circuit boards;
- Measure the size of the key's stem where the joystick will be fitted. This measurement will be performed using a digital caliper;
- Measure the joystick's opening. This measurement will be performed using a digital microscope associated with analytical software;
- The key-joystick assembly will receive a control number;

- After these steps, the joystick will be mounted on the key using the new mounting proposal, with a 45º angle;
- Next the force measurement for removing the joystick from the wrench will be performed;
- All the data will be recorded in a Microsoft Excel table for control purposes and submitted to computer analysis.

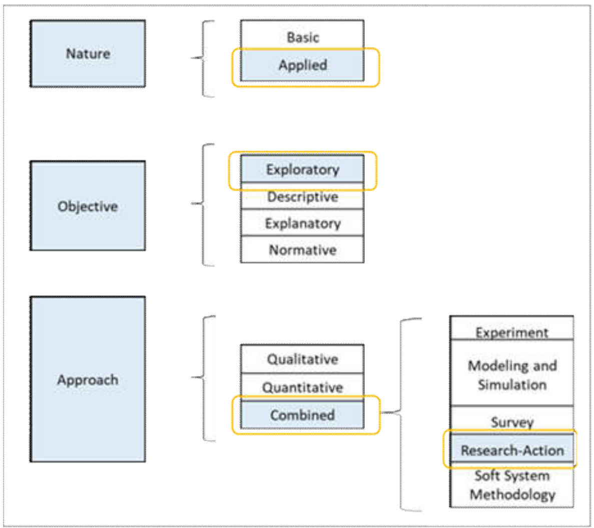


Figure 2. Types of methodology. Source: IVANKOVA, (2014).

Process Flowchart

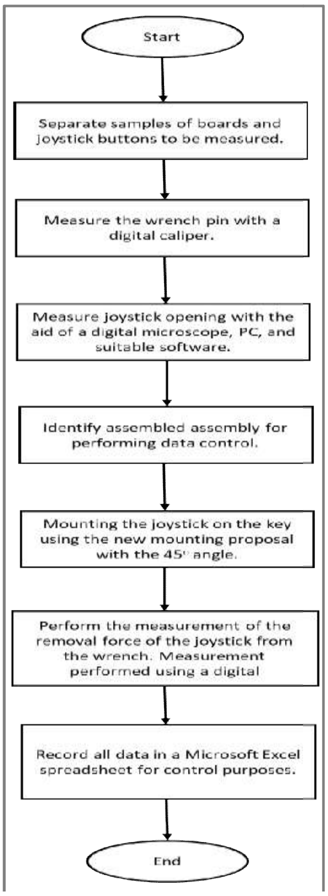


Figure 3. Flowchart of the research Source: Authors, (2021)

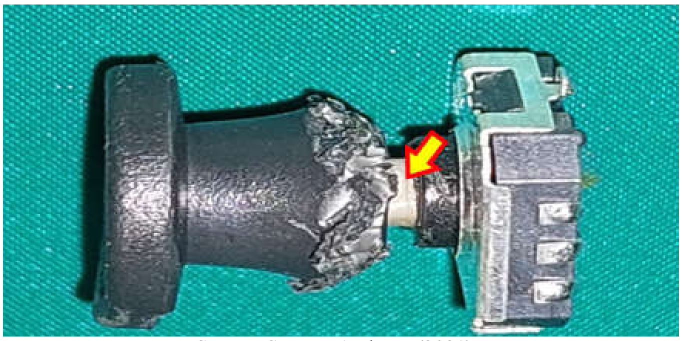
Application of the Case Study

Company Description: The present study takes place in a foreign multinational company producing electronic products - considered one of the largest producers of monitors and televisions in the world. Founded in the 90's, the Brazilian subsidiary is headquartered in the city of Manaus-AM since October 2003. The company's mission is to produce LCD and LED monitors and televisions, of various brands, with the highest technology, providing quality products and an extensive customer service, always aiming at customer satisfaction, with competitive prices and the continuous search for excellence in technological evolution, with the application of an Integrated Management System Policy defined and communicated to all levels of the organization. Since the beginning of its operations in the Manaus Industrial Complex and built in modern facilities, the company has been contributing to the development of the region, which started with 150 jobs and a production capacity, partial, of approximately 25,000 products/month. Currently, the branch has more than a thousand employees and is considered one of the largest producers of televisions in Brazil. The organization where the study was carried out is categorized as a large company. It seeks the development and improvement of its processes through the use of continuous improvement tools, aiming to make its products more competitive in the market. Its production is characterized as an intermittent process, since its volume is determined by demand or batches ordered by large customers, which are commercial, business, or government establishments. The RD (Research and Development) department represented by the NPI (New Product Introduction) team also contributes to the analyses during the pilot line phase. The study evaluates the performance of several products, enumerating the improvements applied by means of PDCA, so that the volume of information obtained was sufficient to generate satisfactory conclusions. The focus of the study is on the phase of introduction of new models and start of mass production, which are developed by the research and development management, with support from the other engineering departments.

Brief description of the problem to be solved: This case study seeks to analyze and apply solutions to design problems encountered during the pilot line phase of an LCD monitor product in OEM (Original Equipment Manufacturer) production process for a renowned company in the area of computer products. In the month of August 2021, the pilot line of a new 24" computer monitor model was carried out. Among other technological resources, this product had as a novelty the use of a joystick button, where normally pressure switches are used. In this design, the model would have to use instant adhesive to keep the joystick mounted on the key-PCB (Printed Circuit Board) assembly. However, the adhesive dripped onto the key body, consequently causing actuation failures. The defect rate was as high as 20.7%.

Figure 4. Adhesion process with Letbond 4461 glue Source: Authors, (2021)

This problem brought productivity losses to the process. The UPH (Unit Produced per Hour) that normally is 540 pieces, suffered a 20% impact, reducing to 432 pieces per hour. There was also a high rate of defects in mass production, whose order was 954 pieces, with rejection of 198 pieces, resulting in 20.7% of defective pieces. The problem also caused high production costs with material costs from the replacement of damaged parts (Joystick, actuation key, solder, adhesive), as well as repair costs, additional direct labor and operating overhead costs.



Source: Source: Authors, (2021).

Figure 5. Migration of the adhesive from the joystick button to the actuation key

Process Losses

In this situation, some costs are tied to the product, such as:

- Material cost derived from the replacement of damaged parts (Joystick, actuation key, solder, adhesive);
- Repair cost represented by resources spent on time, analysis and maintenance of the parts by the repair technician;
- Additional direct labor cost with one more operator to assist with glue insertion to compensate for lost productivity;
- Indirect operational costs by time spent in meetings with areas involved in the decision making process: managers, supervisors, analysts and engineers, besides involving foreign support.

Analysis of the problem

After better understanding the factors and causes surrounding the problem, an Ishikawa Diagram was drawn, showing the probable causes.

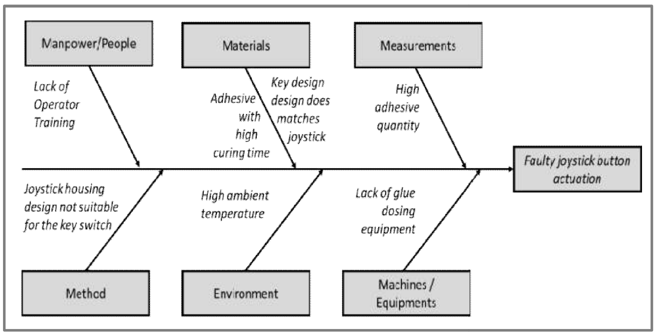


Figure 6. Ishikawa Diagram showing the probable causes Source: Source: Authors, (2021).

By analyzing the Figure above it can be concluded that the main causes of the problems are related to the design problem: "joystick fitting design not suitable for the key button" and "key design does not match joystick", described in the method and materials branches, respectively. Therefore, having the need to make changes in the product design, a small brainstorming with the technical teams was done, and some solutions were proposed:

- Changes in the joystick mold to more accurately fit the key stem on the printed circuit board. This type of action would also demand a high investment. For this reason, it was not accepted by the parent company.
- Developing a new joystick button with a totally new design. This solution would demand the development of a new mold. Approximate cost USD 5.000,00.
- To use another type of adhesive with lower viscosity. For this solution there were no references of a similar product at the time;
- Use a joystick button from another model. In principle, a well accepted proposal, however, the height of this joystick does not fit the product design.

PDCA Cycle

Planning (Plan): Through various attempts and tests, the solutions proposed in the previous session were not taken forward, at least at that time. Instead, it was defined that a simpler and potentially effective solution would be implemented: testing a new way of mounting, where the joystick would be rotated by 45° relative to the button stem, so that the contact key stem would expand inside the internal cavity of the joystick button, according to Figure 7.

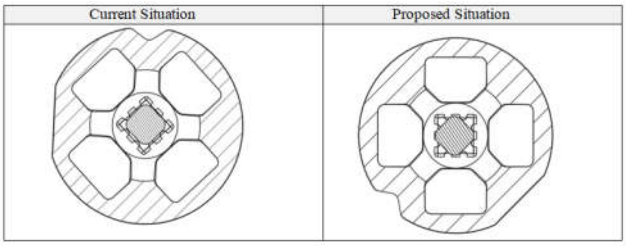


Figure 7. Current and proposed form of joystick button assembly Source: Authors, (2021).

This solution would have some advantages:

- It would not require the inclusion of instant adhesive in the assembly process;
- It would not involve large investments in equipment or molds;
- It would not add costs to the process or to the product;
- It would eliminate the adhesive insertion station.

Despite the advantages listed above, this type of change should be subjected to endurance, functionality, and reliability tests in order to finally obtain management approvals.

Execution (Do)

- Separation of 100 sample pieces of separate boards and joystick buttons was performed.
- The width of the key stem mounted on the PCB was measured using a digital caliper.
- Then the joystick opening was measured using a digital microscope, associated with a PC and application program.
- After this, the assembled sets were identified, in order to perform the data control in a sequential manner;
- Next, the joystick was mounted on the key using the new mounting proposal with a 45º angle.
- Next, the force to remove the joystick from the key was measured. This measurement was performed using a digital dynamometer.
- Finally, for control purposes, all data was recorded in a Microsoft Excel table.

The 100 pieces represent a universe of 10% of what is produced in an average production order.

Verification (Check): After implementing the new process for mounting the joystick on the key at a 45° angle, tests were performed on actuation, fitting and removal force, vibration and drop, and benchmarking with other similar products.

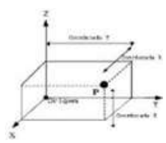
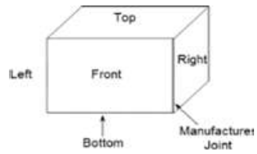
Action (Act): After the planning, assembly and testing phases and the previous steps had been carried out, the data was evaluated and used in the decision-making process and the actions.

Trength and Material Composition: The plastic material that makes up the joystick button is ABS (Acrylonitrile Butadiene Styrene), which is a thermoplastic resin derived from petroleum. ABS is widely used in industry because it is economically viable (relatively low price), lightweight, and easy to mold. It has specific properties such as good impact, tensile, and abrasion resistance (friction wear; scraping). When compared to other materials ABS plastic has some resistance to heat and low temperatures, and can normally be used at temperatures ranging from -20°C to 80°C. In addition, it also functions as an electrical insulator. ABS plastic molding can be processed by injection molding or extrusion, ensuring a consistent interlayer connection and minimal deformation. The stem of the drive key is composed of high-performance aliphatic polyamide with a melting temperature of 295°C and which, due to its high crystallization and fast crystallization speeds, has excellent high-temperature mechanical performance and good wear and friction properties.

OBTAINED RESULTS

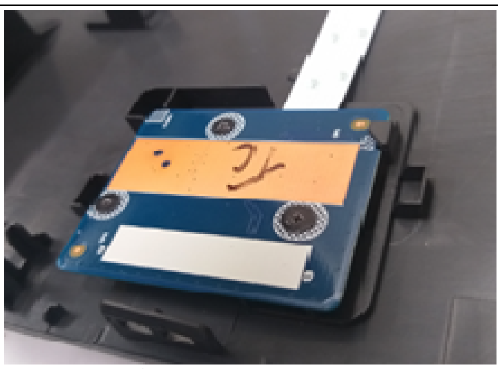
Vibration and drop tests: Due to the destructive nature of the vibration and drop tests, a quantity of 5 pieces were used to check if the assembly in this condition does not present risks of disassembly or spontaneous disconnection in situations of transportation or impact of the assembled product with external factors. The tests are directed at strategic corners, such as front and back faces, corners, and diagonals of products in their respective boxes.

More details are described in Figure 8:

Product:	Monitor	
Model:	X24	
Phase:	Joystick button mounting analysis when mounted without adhesive	
DROP AND VIBRATION TEST		
Vibração		Queda
		 Top, Left, Front, Right, Bottom, Manufacturer Joint
Drop & Vibration Test		
Serial	**Final Result**	**Remarks**
BR067NW4TVB0018J0C0L BR067NW4TVB0018J0D6L BR067NW4TVB0018J0EIL BR067NW4TVB0018J0B8L BR067NW4TVB0018J0DUL	**APPROVED** **08/28/2021**	**The products withstood the impact of vibration and drop tests, with no damage to the joystick button**

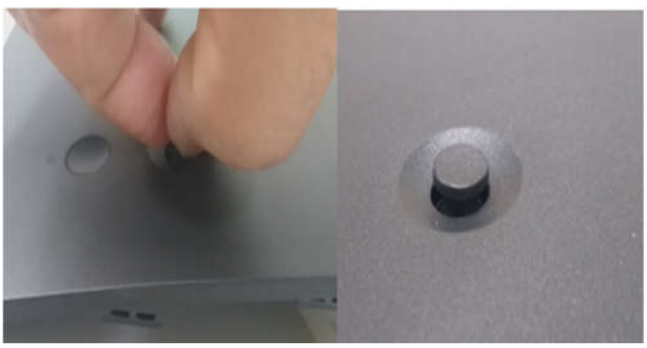
Source: Authors, (2021)

Figure 8. Vibration and drop test results



Source: Authors, (2021).

Figure 9. Assembly mounted in the product cabinet



Source: Pictures obtained from the company's production process (2021).

Figure 10. Simulation of joystick removal in the assembled cabinet

Release Testing: Considering that in the product, the group assembly is enclosed by the back cover, it is possible to verify that the joystick button's detachment is prevented by the product structure. In a hypothetical situation, such as a customer pulling the joystick until it comes out of the actuation key slot, a minimum form of 0.6KgF would be required. Even so, it is not possible to separate the button from the product. In order to verify a relationship between key stem measurements, cavity measurements, and joystick removal force, were made measurements on 100 parts using various instruments, such as caliper and digital microscope. The complete procedure is recorded in Section Survey Methodology.

Benchmarking: As a reference to verify that the measurements of the joystick knob rotation experiment are within an acceptable standard, the measurements of another similar model were recorded. Pictures of the key and joystick knob of the similar model are shown in Figure 11.

Application of Fuzzy Logic for Decision Making: In order to find mathematical patterns and correlations between the measured values, as well as ways to facilitate the analysis and decision making process, some computational tools can be applied, such as: Fuzzy Logic, Genetic Algorithms and Artificial Neural Network (ANN). In this article, Fuzzy Logic will be used.

Application of Fuzzy Logic: Based on the measurements made on the parts of the product with improved design and also on the benchmark parts, and defined the evaluation parameters, it was possible to create a fuzzy system with their respective input and output variables. Based on the measurements recorded in Tables 4 and 5, a classification of the measured drive button stem parameters was generated, based on the criteria: VERY LOW, LOW, MEDIUM, HIGH, and VERY HIGH.

The graphical representation of the evaluation criteria for the actuation button stem measurements can be determined by a set of linguistic parameters, which are: Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH).

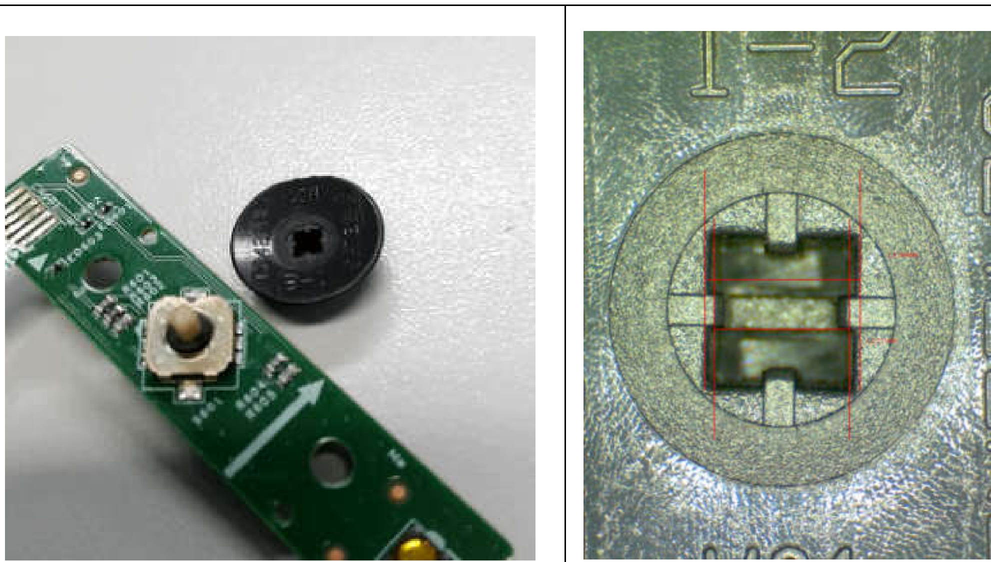
Table 1. Measurements of the key stem, cavities, and removal force

Part	Actuation key stem (A)	Joystick Cavity (C)	Gap = A - C (before correction)	Diagonal of the stem $D^2 = (h)^2 + (h)^2$	Delta Δ = D-h	Expansion of the rod at 45° (correction) = Δ/2-Gap	Removal force (KgF)
1	1,93	2,00	-0,07	2,73	0,80	0,33	1,01
2	1,91	2,04	-0,13	2,70	0,79	0,27	0,87
3	1,90	2,04	-0,14	2,69	0,79	0,25	1,97
4	1,91	2,09	-0,18	2,70	0,79	0,22	1,92
5	1,90	2,06	-0,16	2,69	0,79	0,23	0,88
6	1,91	2,09	-0,18	2,70	0,79	0,22	0,65
7	1,90	2,07	-0,17	2,69	0,79	0,22	1,45
8	1,93	2,11	-0,18	2,73	0,80	0,22	1,81
9	1,92	2,11	-0,19	2,72	0,80	0,21	1,39
10	1,92	2,10	-0,18	2,72	0,80	0,22	1,40
11	1,91	2,09	-0,18	2,70	0,79	0,22	1,14
12	1,90	2,10	-0,20	2,69	0,79	0,19	0,63
13	1,93	2,01	-0,08	2,73	0,80	0,32	0,56
14	1,93	1,98	-0,05	2,73	0,80	0,35	1,23
15	1,95	2,03	-0,08	2,76	0,81	0,32	1,39
16	1,92	2,05	-0,13	2,72	0,80	0,27	1,75
17	1,93	2,10	-0,17	2,73	0,80	0,23	1,55
18	1,93	2,01	-0,08	2,73	0,80	0,32	0,96
19	1,94	2,03	-0,09	2,74	0,80	0,31	0,53
20	1,94	2,05	-0,11	2,74	0,80	0,29	1,20
21	1,94	2,06	-0,12	2,74	0,80	0,28	0,88
22	1,94	2,03	-0,09	2,74	0,80	0,31	1,51
23	1,95	2,03	-0,08	2,76	0,81	0,32	1,77
24	1,95	2,03	-0,08	2,76	0,81	0,32	1,58
25	1,90	2,19	-0,29	2,69	0,79	0,10	0,78
26	1,95	1,97	-0,02	2,76	0,81	0,38	1,11
27	1,91	2,00	-0,09	2,70	0,79	0,31	0,67
28	1,91	1,98	-0,07	2,70	0,79	0,33	0,51
29	1,94	2,02	-0,08	2,74	0,80	0,32	1,04
30	1,94	1,97	-0,03	2,74	0,80	0,37	1,67
31	1,91	2,03	-0,12	2,70	0,79	0,28	2,03
32	1,90	2,01	-0,11	2,69	0,79	0,28	1,08
33	1,89	2,02	-0,13	2,67	0,78	0,26	0,74
34	1,90	2,06	-0,16	2,69	0,79	0,23	0,79
35	1,89	2,02	-0,13	2,67	0,78	0,26	0,77
36	1,89	2,01	-0,12	2,67	0,78	0,27	0,89
37	1,91	1,98	-0,07	2,70	0,79	0,33	1,79
38	1,91	2,05	-0,14	2,70	0,79	0,26	1,08
39	1,91	2,01	-0,10	2,70	0,79	0,30	0,63
40	1,89	1,97	-0,08	2,67	0,78	0,31	0,86
41	1,91	2,03	-0,12	2,70	0,79	0,28	1,00
42	1,88	2,03	-0,15	2,66	0,78	0,24	0,89
43	1,90	1,98	-0,08	2,69	0,79	0,31	0,87
44	1,89	1,97	-0,08	2,67	0,78	0,31	0,80
45	1,90	1,97	-0,07	2,69	0,79	0,32	1,46
46	1,90	1,97	-0,07	2,69	0,79	0,32	1,43
47	1,91	1,93	-0,02	2,70	0,79	0,38	1,85
48	1,89	1,92	-0,03	2,67	0,78	0,36	0,74
49	1,90	1,96	-0,06	2,69	0,79	0,33	0,70
50	1,91	1,97	-0,06	2,70	0,79	0,34	0,66
51	1,90	2,00	-0,10	2,69	0,79	0,29	0,73
52	1,91	1,97	-0,06	2,70	0,79	0,34	0,70
53	1,91	1,94	-0,03	2,70	0,79	0,37	1,56
54	1,90	1,93	-0,03	2,69	0,79	0,36	1,64
55	1,91	1,97	-0,06	2,70	0,79	0,34	1,39
56	1,90	1,96	-0,06	2,69	0,79	0,33	0,70
57	1,93	1,96	-0,03	2,73	0,80	0,37	0,98
58	1,88	1,96	-0,08	2,66	0,78	0,31	0,74
59	1,92	1,96	-0,04	2,72	0,80	0,36	0,73
60	1,89	1,97	-0,08	2,67	0,78	0,31	0,62
61	1,91	1,91	0,00	2,70	0,79	0,40	1,66
62	1,92	1,97	-0,05	2,72	0,80	0,35	2,11
63	1,91	1,94	-0,03	2,70	0,79	0,37	1,39
64	1,92	2,00	-0,08	2,72	0,80	0,32	0,52
65	1,87	2,00	-0,13	2,64	0,77	0,26	0,70
66	1,89	1,92	-0,03	2,67	0,78	0,36	1,60
67	1,88	2,00	-0,12	2,66	0,78	0,27	0,76
68	1,89	1,89	0,00	2,67	0,78	0,39	0,64
69	1,90	1,95	-0,05	2,69	0,79	0,34	1,16
70	1,90	1,89	0,01	2,69	0,79	0,40	1,31
71	1,92	1,97	-0,05	2,72	0,80	0,35	1,29

Continue ….

72	1,89	1,89	0,00	2,67	0,78	0,39	0,77
73	1,90	1,96	-0,06	2,69	0,79	0,33	0,77
74	1,90	1,98	-0,08	2,69	0,79	0,31	0,95
75	1,90	1,98	-0,08	2,69	0,79	0,31	0,83
76	1,89	1,96	-0,07	2,67	0,78	0,32	0,51
77	1,90	1,93	-0,03	2,69	0,79	0,36	1,64
78	1,92	1,98	-0,06	2,72	0,80	0,34	1,73
79	1,91	1,98	-0,07	2,70	0,79	0,33	1,19
80	1,87	1,97	-0,10	2,64	0,77	0,29	0,57
81	1,89	1,92	-0,03	2,67	0,78	0,36	0,99
82	1,89	1,92	-0,03	2,67	0,78	0,36	0,80
83	1,89	1,97	-0,08	2,67	0,78	0,31	1,05
84	1,91	1,96	-0,05	2,70	0,79	0,35	0,63
85	1,91	1,96	-0,05	2,70	0,79	0,35	1,50
86	1,91	1,93	-0,02	2,70	0,79	0,38	1,28
87	1,90	1,93	-0,03	2,69	0,79	0,36	1,00
88	1,89	1,97	-0,08	2,67	0,78	0,31	0,98
89	1,89	1,97	-0,08	2,67	0,78	0,31	0,76
90	1,89	2,05	-0,16	2,67	0,78	0,23	0,54
91	1,89	2,00	-0,11	2,67	0,78	0,28	0,75
92	1,91	1,94	-0,03	2,70	0,79	0,37	0,64
93	1,90	2,00	-0,10	2,69	0,79	0,29	0,80
94	1,91	1,96	-0,05	2,70	0,79	0,35	1,39
95	1,91	1,98	-0,07	2,70	0,79	0,33	1,23
96	1,88	1,96	-0,08	2,66	0,78	0,31	0,61
97	1,89	1,97	-0,08	2,67	0,78	0,31	0,72
98	1,88	1,96	-0,08	2,66	0,78	0,31	0,75
99	1,89	1,97	-0,08	2,67	0,78	0,31	1,16
100	1,88	1,97	-0,09	2,66	0,78	0,30	0,96
Average	1,91	1,99	-0,09	2,70	0,79	0,31	1,07

Source: Authors, (2021).



Source: Authors, (2021)

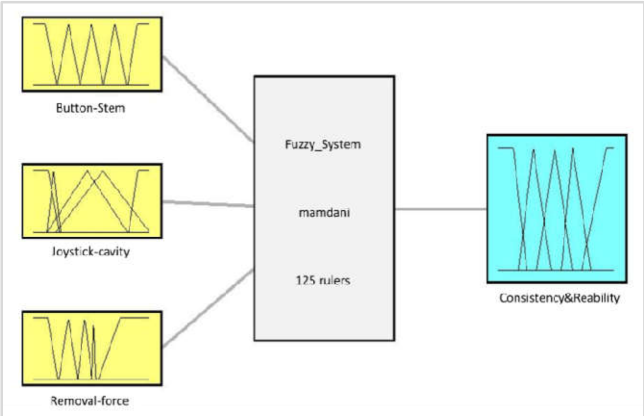
Figure 11. Benchmarking with similar model

Table 2. Benchmarking with similar model measures

Part	Actuation key stem (A)	Joystick Cavity (C)	Delta Δ = A – C (tightness)	Removal force (KgF)
1	1,91	1,83	0,08	1,02
2	1,90	1,88	0,02	0,99
3	1,91	1,87	0,04	1,20
4	1,94	1,87	0,07	1,20
5	1,90	1,86	0,04	0,86
6	1,89	1,86	0,03	0,85
7	1,89	1,87	0,02	1,36
8	1,89	1,86	0,03	1,07
9	1,89	1,87	0,02	1,36
10	1,93	1,87	0,06	1,22
Average	**1,91**	**1,86**	**0,04**	**1,11**

Source: Authors, (2021).

The classification of the parameters measured in the joystick cavity and with similar criteria as the previous item, are recorded in Table 7. The graphical representation of the evaluation criteria for the joystick cavity measurements can be determined by a set of linguistic parameters, which are: Very Low (ML), Low (L), Medium (M), High (H), and Very High (VH).



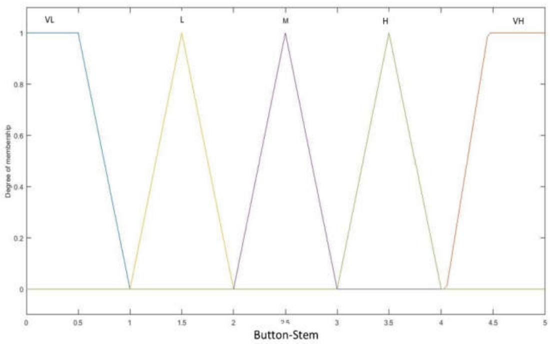
Source: Authors, (2021).

Figure 12. Fuzzy system for the evaluation of the part measurements

Table 3. Criteria for evaluating the measurements of the actuation button stem

Classification	Measured Range
VERY LOW	1,87 ~ 1,89
LOW	1,98 ~ 1,91
MEDIUM	1,91 ~ 1,92
HIGH	1,92 ~ 1,94
VERY HIGH	1,94 ~ 1,95

Source: Authors, (2021).



Source: Authors, (2021).

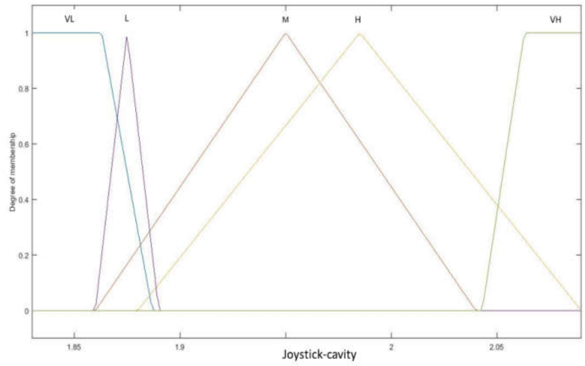
Figure 13. Graphical representation of the stem evaluation criteria

Table 4. Evaluation criteria for the joystick cavity measurements

Classification	Measured Range
VERY LOW	1,83 ~ 1,89
LOW	1,86 ~ 1,89
MEDIUM	1,86 ~2,04
HIGH	2,04 ~ 2,09
VERY HIGH	1,88 ~ 2,09

Source: Authors, (2021).

The classification of the parameters measured in the removal force and with similar criteria as the previous item, are recorded in Table 5. As is characteristic of fuzzy systems, the graphical representation of the evaluation criteria for the joystick button removal force can be determined by a set of linguistic parameters, which are: Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH).



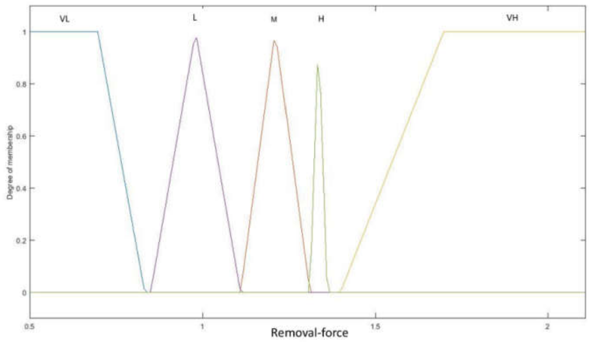
Source: Authors, (2021)

Figure 14. Evaluation criteria for the joystick cavity measurements

Table 5. Removal force of the joystick button after improvement

Classification	Measured Range
VERY LOW	0,51 ~ 0,85
LOW	0,85 ~ 1,11
MEDIUM	1,11 ~ 1,31
HIGH	1,31 ~ 1,36
VERY HIGH	1,36 ~ 2,11

Source: Authors, (2021).



Source: Authors, (2021).

Figure 15. Graphical representation of the strength assessment criteria

Based on the evaluation functions and input and output variables, 125 inference rules are generated. Table 6 was generated by evaluating the three input parameters and obtained from expert analysis

Considering formula:

$$R = N^{v} \tag{1}$$

Where:

R is the number of rules;
N is the number of inferences;
v is the number of variables.

Then:

$$R = 5^3$$

$$R = 125$$

The legend used is the following

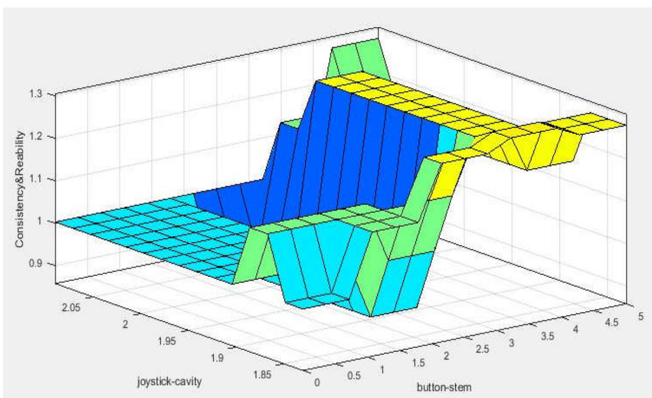
- VL: Very Low
- L: Low
- M: Medium
- H: High
- VH: Very High

Table 6. Inference rules based on input and output variables

Combination	Stem	Joystick	Force	Consistency/Reliability
1	VL	VL	VL	VL
2	VL	L	VL	VL
3	VL	M	VL	VL
4	VL	H	VL	VL
5	VL	VH	VL	VL
6	L	VL	VL	VL
7	L	L	VL	VL
8	L	M	VL	VL
9	L	H	VL	VL
10	L	VH	VL	VL
11	M	VL	VL	L
12	M	L	VL	L
13	M	M	VL	VL
14	M	H	VL	VL
15	M	VH	VL	VL
16	H	VL	VL	L
17	H	L	VL	L
18	H	M	VL	L
19	H	H	VL	VL
20	H	VH	VL	L
21	VH	VL	VL	M
22	VH	L	VL	M
23	VH	M	VL	M
24	VH	H	VL	L
25	VH	VH	VL	L
26	VL	VL	L	L
27	VL	L	L	L
28	VL	M	L	VL
29	VL	H	L	VL
30	VL	VH	L	VL
31	L	VL	L	L
32	L	L	L	L
33	L	M	L	VL
34	L	H	L	VL
35	L	VH	L	VL
36	M	VL	L	M
37	M	L	L	M
38	M	M	L	L
39	M	H	L	L
40	M	VH	L	VL
41	H	VL	L	VL
42	H	L	L	M
43	H	M	L	M
44	H	H	L	L
45	H	VH	L	L
46	VH	VL	L	M
47	VH	L	L	M
48	VH	M	L	M
49	VH	H	L	M
50	VH	VH	L	L
51	VL	VL	M	L
52	VL	L	M	M
53	VL	M	M	L
54	VL	H	M	L
55	VL	VH	M	L
56	L	VL	M	L
57	L	L	M	L
58	L	M	M	L
59	L	H	M	L
60	L	VH	M	L
61	M	VL	M	M
62	M	L	M	M
63	M	M	M	L
64	M	H	M	L
65	M	VH	M	VL
66	H	VL	M	M
67	H	L	M	M
68	H	M	M	M
69	H	H	M	L
70	H	VH	M	M
71	VH	VL	M	M
72	VH	L	M	M
73	VH	M	M	M
74	VH	H	M	M
75	VH	VH	M	L
76	VL	VL	H	L
77	VL	L	H	L
78	VL	M	H	L
79	VL	H	H	L
80	VL	VH	H	L
81	L	VL	H	M
82	L	L	H	L
83	L	M	H	L
84	L	H	H	L
85	L	VH	H	VL
86	M	VL	H	M
87	M	L	H	M
88	M	M	H	M
89	M	H	H	L
90	M	VH	H	L
91	H	VL	H	H
92	H	L	H	H
93	H	M	H	H
94	H	H	H	M
95	H	VH	H	M
96	VH	VL	H	H
97	VH	L	H	H
98	VH	M	H	H
99	VH	H	H	M
100	VH	VH	H	M
101	VL	VL	VH	M
102	VL	L	VH	M
103	VL	M	VH	M
104	VL	H	VH	M
105	VL	VH	VH	M
106	L	VL	VH	H
107	L	L	VH	M
108	L	M	VH	M
109	L	H	VH	M
110	L	VH	VH	M
111	M	VL	VH	VH
112	M	L	VH	VH
113	M	M	VH	M
114	M	H	VH	M
115	M	VH	VH	M
116	H	VL	VH	VH
117	H	L	VH	VH
118	H	M	VH	H
119	H	H	VH	M
120	H	VH	VH	M
121	VH	VL	VH	VH
122	VH	L	VH	VH
123	VH	M	VH	VH
124	VH	H	VH	H
125	VH	VH	VH	H

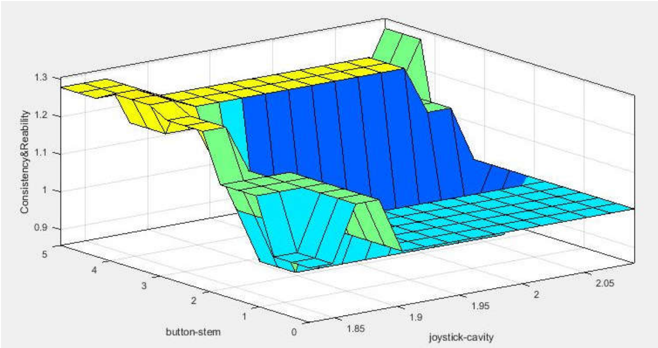
Source: Authors, (2021).

Based on the established set of rules, fuzzy logic inference provides the consistency/reliability results according to any combination of the input parameters. These combinations are represented in the three-dimensional (3D) surface graphs in Figures 16, 17 and 18.



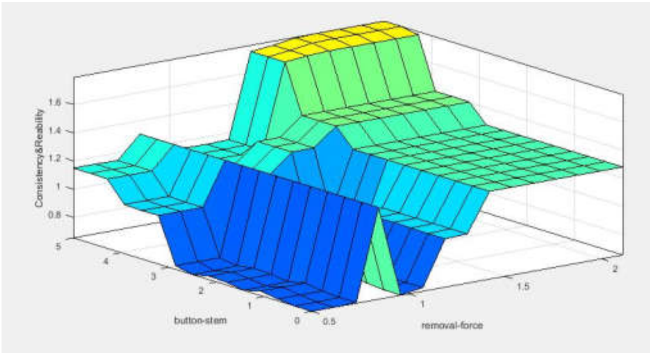
Source: Authors, (2021).

Figure 16. Consistency/reliability versus cavity vesus stem



Source: Authors, (2021).

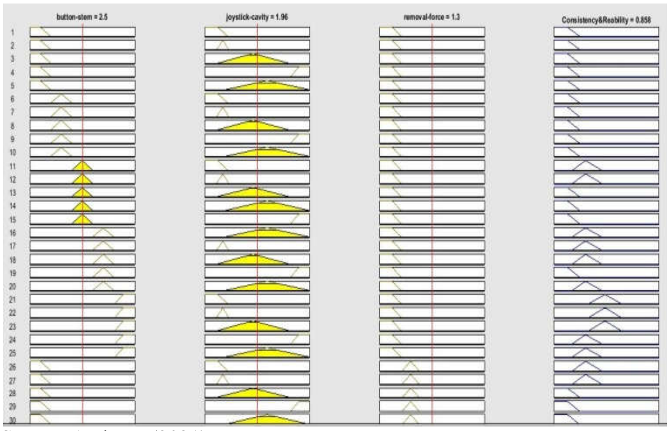
Figure 17. Consistency/reliability versus stem vesus cavity



Source: Authors, (2021).

Figure 18. Consistency/reliability versus stem vesus strength

The consistency/reliability values are calculated based on the inference rules established, from the three parameters (stem, cavity and force) using the Fuzzy logic inference system, as shown in the Figure below:



Source: Authors, (2021).

Figure 19. Overview of the inference rules via fuzzy system.

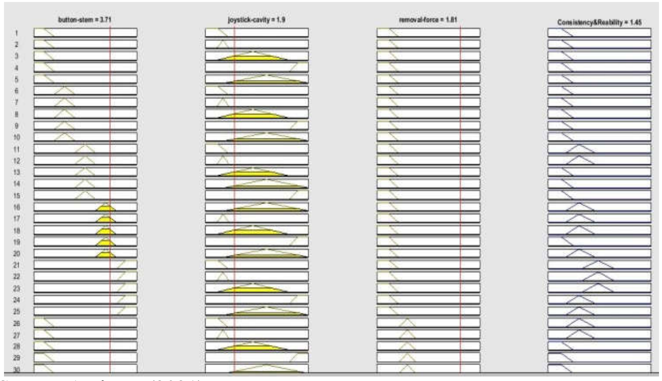
The fuzzy logic model calculates the different consistency/reliability scenarios and provides a different result for scenarios. For example, the default value found in the final result was 0.868 (considering stem = 2.5, cavity = 1.96 and force = 1.3).

Suppose that the value of the measurements of the stem, cavity and force assumed critical values (1.21, 2.05 and 0.658, respectively), the result would be 0.706, representing a low consistency and reliability of the system.

But assuming that the values of the measurements of the stem, cavity, and force took on values considered reasonable (3.71, 1.9, and 1.81, respectively), the result would be 1.46, representing optimum system consistency and reliability.

Source: Authors, (2021).

Figure 20. Result representing low consistency and reliability

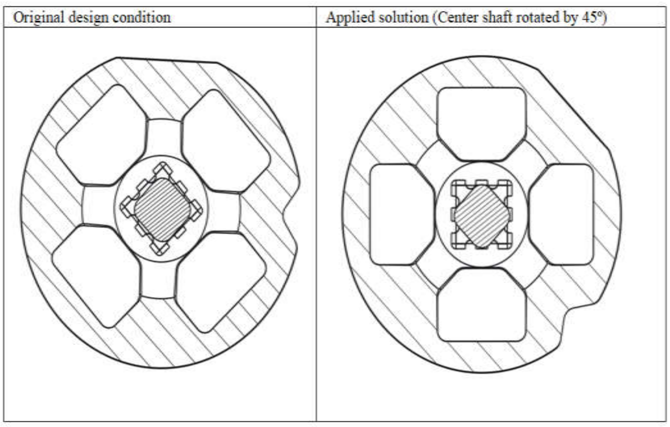


Source: Authors, (2021).

Figure 21. Result representing optimal consistency and reliability

Other aspects

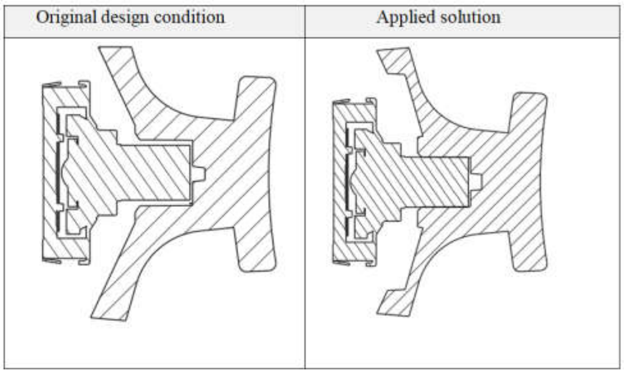
Contact area: In the original design, the contact area between the joystick and key stem is minimal (or none at all) due to the measurements of the joystick stem and joystick cavity being very close together.



Source: Authors, (2021).

Figure 22. Comparison (without and with application of the proposed solution)

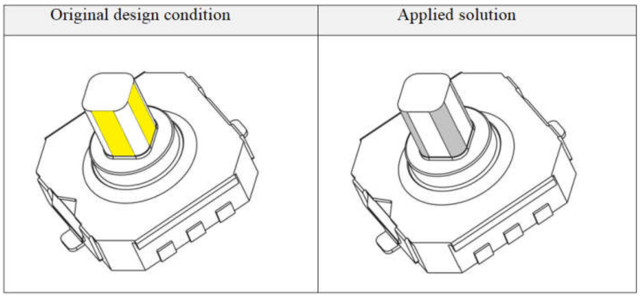
When observing the system from a side angle, it becomes more noticeable to observe the differences that exist between the two configurations. In the first image in Figure 23 it is visible that there is no contact between the central rod and the joystick, justifying the need for adhesive. In the second image where the solution is applied (central rod axis rotated by 45°), there is strong contact between the central axis and the joystick, requiring no adhesive.



Source: Authors, (2021).

Figure 23. Comparison (without and with application of the proposed solution)

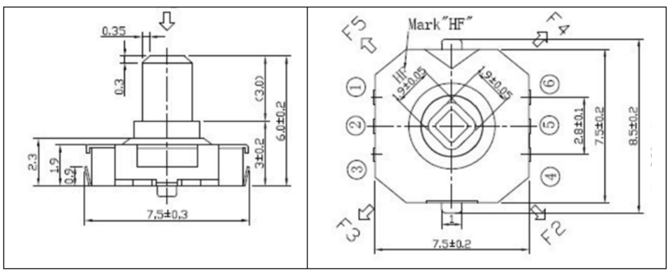
In Figure 24, the yellow area shows the place where theoretically there should be contact between the stem and the joystick. In the adjacent image, the gray area illustrates the contact area between the rod and the joystick button.



Source: Authors, (2021).

Figure 24. Comparison (without and with application of the proposed solution)

Considering the information contained in the part specifications (Figure 25), the approximate value of the contact area (gray area in Figure 24) can be calculated.



Source: Authors, (2021).

Figure 25. Dimensions of the drive key

$$A = B * h * l \quad (2)$$

Where:

A is the contact area;

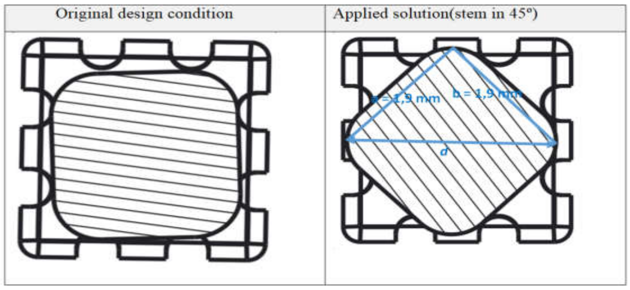
B is the value of the base, or that, the width of the gray area;
l is the number of sides where there is contact (gray area).

$$A = (1.99 - 0{,}35) * 3 * 4$$

$$A = 1{,}64 * 12$$

$$A = 19{,}68 \text{ mm}^2$$

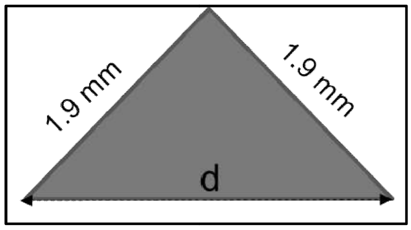
Expansion: Considering that the cross section of the contact wrench stem is shaped like a square with rounded edges, the expansion zone can be calculated as the hypotenuse of a rectangle triangle.



Source: Authors, (2021).

Figure 26. Comparison (without and with application of the proposed solution)

For better understanding, the area corresponding to the rectangle triangle was separated for analysis according to Figure 27:



Source: Authors, (2021).

Figure 27. Equating part of the key's stem to a rectangle triangle

To calculate the expansion area, you need to follow these steps:

1. Calculate the value of "*d*"

$d^2 = a^2 + b^2$
$d^2 = (1.9)^2 + (1.9)^2$
$d^2 = 3.61 + 3.61$
$d = \sqrt{7{,}22}$
$d = 2.68$ mm

2. Next, the value of the lateral measurement, which is 1.9 mm, must be subtracted. In this operation the total expansion is calculated.

Total Expansion = d – 1.9
Total Expansion = 2.68 – 1.9
Total Expansion = 0.78

3. Since the total expansion considers both sides, it must be divided by 2 to calculate how much the rod enlarges to the sides on each side when it is rotated by 45°.

Side expansion = 0.78/2
Side expansion = 0.39 mm

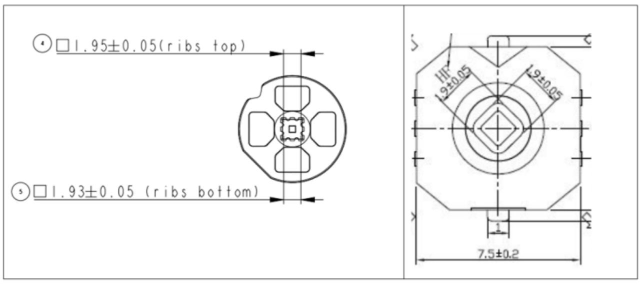
Considering the tolerances specified in Figure 27, the expansion values can vary from 0.36 m to 0.41 mm. Based on the above calculations, the measurement of the expansion after rotation can be determined by the formula below:

$$Expansion = (\sqrt{2b^2} - a) / 2 \quad (3)$$

Where:

b is the measurement of the width of the actuation button stem;
a is the measurement of the joystick button opening
Note: As stated before, the need to divide by 2 occurs because the expansion takes place at both ends of the right triangle that forms when the pushbutton rod is rotated by 45°.

Minimum critical value after improvement: Considering the maximum opening value of the joystick cavity and the minimum value of the actuation button stem width, it is possible to calculate the minimum stem expansion value when rotated by 45°:



Source: Authors, (2021).

Figure 28. Specifications of the joystick button and actuation button stem

Maximum joystick opening measurement = 1,95+0,05 = 2,00 mm (a)
Minimum dimension of the actuation button stem width = 1,9-0,05 = 1,85 mm (b)

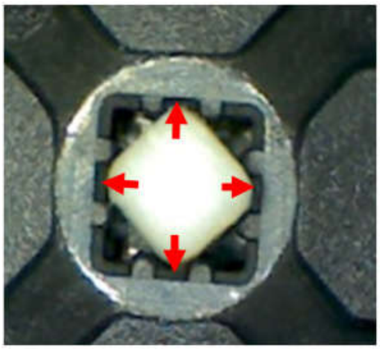
Measurement of the expansion after rotation:

$(\sqrt{2b^2}) - a)/2 \quad (4)$

$= (\sqrt{2 * (1{,}85)^2}) - 2)/2 = (2{,}61 - 2)/2 = 0{,}3$ mm.

The above result shows that even in a critical situation - when the joystick opening is at its maximum extent and the wrench stem is at its minimum extent - there will always be traction between these two components because of the minimum expansion of 0.3 mm.

Traction: The expansion of 0.39 mm in each of the transverse vertices of the contact key rod generates a removal force of 1 kg.F that is distributed among the 4 vertices of the internal pin, that is, 0.25 Kg.F on each side.



Source: Authors, (2021).

Figure 29. Traction points in the stem/joystick system

Considering the formula:

$Ft = \mu N \quad (5)$

The coefficients of friction in polymers sliding against themselves, or against metals or ceramics are in the range 0.1 to 0.5. Using an average value of 0.3, the normal force (N) in this system can be calculated as follows:

$Ft = \mu N$
$1{,}073 = 0{,}3 * N$
$N = 3{,}576$ N

Where:

Ft is the force of traction
μ is the coefficient of friction
N is the normal force

DISCUSSION

With the implementation of the proposed solutions, the following results were achieved:

- Solution of design problems, with reduction of Fail Of Rate (F.O.R.) from 20% to 3%;
- Reduction of costs with spare parts (adhesive, welding, joystick buttons and actuation keys);
- Reduction of costs and time with labor performed by specialized technician in repair services of defective parts;
- Improvement of quality and productivity indicators;
- Improvement of environmental aspects with the elimination or reduction of the use of adhesive in the product;
- Reduction of health risks to the operators, once the use of instant adhesive in the process was reduced.
- Optimization of the manufacturing process by consequently reducing the number of assembly stations. In this case, the result occurred due to the optimization of the joystick assembly station.

CONCLUSION

This case study explored the implementation of a new LCD monitor product design with the application of quality tools as a facilitator for solving assembly problems. The work was developed in an assembly industry of monitors and televisions located in the Manaus Free Trade Zone. In addition, the PDCA (Plan, Do, Check, Action) method was used as the main tool for analysis and application of solutions, followed by the use of the Ishikawa Diagram and the application of Kaizen, in which it was possible to implement improvements in the product design, specifically in the assembly phase of the joystick button with the key switch stems. As a final result, the following benefits were achieved: solution of the assembly problem, with a significant reduction of the defect rate from 20% to 3%, reduction of costs with spare parts and repair service of around 1%. Besides this, there was a 17% increase in the quality rates, and an improvement in the productivity indicators.

THANKS

To the Graduate Program in Engineering, Process Management, Systems and Environment at the Galileo Institute of Technology and Education in the Amazon (PPG.EGPSA/ITEGAM) for their support to search.

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