Development of a Mechanical Sleeve Diagnosis Test

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***Abstract*— This paper presents the development of a system to assist the inspection, repair and calibration of mechanical sleeves. This system contemplates a mechanical device and the underlying software in which the main data acquisition is carried out through a force sensor. The developed system implied the development of specific hardware, based on the platform Arduino, and dedicated software based on C programming language. A user interface to register and store the fulfilled tests was developed. The system allowed to optimize the performance and the efficiency of a manufacturing unit, which, until now, was done using a manual procedure.**

Keywords-sleeve; nozzle; force sensor; Arduino.

I. INTRODUCTION

This section presents the state or art, the motivation and the background of the project, as well as its purposes and the paper structure.

A. State of Art

Verhagen et al. (2015) [1] argue that automation of engineering processes is increasingly prevalent in multiple lifecycle phases such as design, manufacturing and service. The automation of physical tasks is a long-standing characteristic of enterprises striving to remain competitive. For mass production systems in particular, the majority of manual labour has been replaced by automated production equipment, a trend that is increasingly replicated in series production systems.

Limoncelli (2016) [2] tells that care should be taken when a process is automated because the human component of the process could be very important for the entire system. “When a process is automated the automation encapsulates learning thus far, permitting new people to perform the task without having to experience that learning.”

Luz and Kuiawinski (2006) [3] expose that, with the industry evolution, relevant events were observed in the development of Production Engineering settings and the presence of the machines, manufacturing processes and production systems increased. Using these concepts, expanded methods have been created to the other branches of the organization, such as the commercial and services branches.

Zuboff (1994) [4] quoting H. L. Arnold, an industrial journalist, wrote with excitement about Ford’s innovations that maximize the continuity of the assembly. He summarized the main elements of that productivity strategy, initially, all unnecessary movements were eliminated from the actions of the workers. The task was organized in order to require the least amount of will power consumption and mental effort.

From the above, it can be assumed that automating a manual process can be very advantageous although it should be pondered if this action is beneficial to the company as it is to the human element. In the case of this paper, it will be clearly demonstrated that the developed system brings numberless advantages to both sides because it will reduce the error margin and increase the efficiency, resulting in an increase of effective working time of the operator.

B. Motivation and Background

The motivation associated with this study fits in upgrading/automating a mechanical sleeves test procedure of a multinational technological company, located in the city of Braga, northern Portugal. The sleeves are used by an electronic components assembly industrial machine; this machine controls the segments in order to pick the components and drop them in the right place of a PCB (printed circuit board). They have a spring inside with a defined pressure, which is responsible for absorbing the impact of SMD components (Surface Mounting Devices) both in the collection as well as in the placement. The state of this spring is critical to ensure the components application accuracy as well as to prevent the rejection of the electronic components. The spring pressure can only be applied after placing a nozzle (Fig. 1).

The previous method that was used for the detection of the spring state was a manual process using a testing instrument in which the result of the applied force in the spring was shown using a manometer. To observe that, some individual weights of 200 g each were used, who exercise force exclusively on the spring. The pointer of the manometer must be between 15 and 25, resulting in a maximum force applied of 2.2 N. That range is recommended by the buyer which is also the manufacturer of

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the industrial machine referenced above. This measurement system has no units which gives a non-scientific approval.

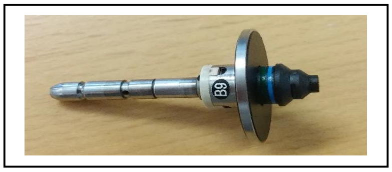

Figure 1. Example of a sleeve with the nozzle applied.

C. *Project purposes*

As the manual diagnostic test is a time consuming process and it may not offer the same test conditions to all sleeves - this is a consequence of the weights that might be dropped at different heights resulting in a change in the force exerted in the spring. So, to address these issues, the purpose of this project is to develop a device associated with a graphical application, allowing direct contact between the data acquired with the operator, which results into less manual labour on the side of the user.

This project contemplates two main parts, hardware and software. The hardware to be developed will comprise:

- A support structure to backing the tool in the repair bench;
- A motor for controlling the force to apply to the sleeve to be evaluated;
- A sensor for measuring strength and all electronic components required.

The software to be developed should provide:

- An interface for interaction with the operator to control and analysis of the measures;
- Graphical presentation of the force measured;
- Organization and storage of the data acquired.

D. *Paper structure*

This paper is structured in 4 sections. In the second section, Technical Description, the problem analysis is presented as well as the way it was approached, demonstrating how problems were solved and which are the reasons that led to the chosen solutions. This section exposes the most important points of the development of this project. In the third section, Final Tests and Installation, we describe the final tests carried out and the method how the installation of the device was executed in production. In the fourth section, Conclusion and Future Work, we present the conclusions of the work carried out, as well as indicate some improvement proposals.

II. TECHNICAL DESCRIPTION

The problem to be solved arises from the need to replace the manual performed sleeve spring diagnostic test that, can be susceptible to human error, for a new device capable to streamline resulting in a more organized process as well as the integration of more and new features.

It was established a strategy of resolution of the problem. In the broadest sense of the problem, the following block diagram was developed (Fig. 2).

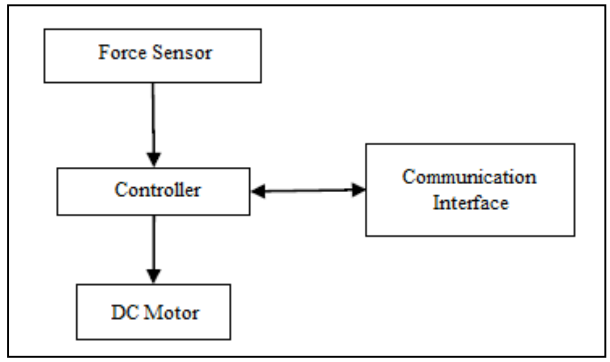

Figure 2. Project block diagram.

As presented in Fig. 2, the data provided by the sensor should be treated by the controller and sent to the interface; the motor which represents the motion of the sleeve, receives orders from the controller that can either be subsequent of sensor data or orders from the operator through the interface. In order to store the information of each tested segment as well to include the date of the tests, there was a need to integrate a database in the software application.

A. *System Design*

In a first approach to the project it was necessary and important to perform several manual diagnostic tests to understand the whole process from scratch. If the test is invalid, it is necessary to repair the sleeve by changing the spring or, in some cases, by cleaning the inside of the sleeve, which is enough to restore the correct functionality of the spring.

Once defined the resolution strategy it was crucial to begin the research about the sensor to use knowing that, it would be important to measure the force intensity applied in Newton (N) [5, 6].

After a research of existing sensors in the market that could supply this project needs, we considered the force sensor reference FSG015WNPB from Honeywell (Fig. 3) [6]. This sensor has a plunger area, a total volume of 916,16 mm^3, a measurement range between 0 to 15N, a value of 0,5% span relativity to linearity and 0,2% of span relativity to repeatability, in order to detect the small force oscillations of the sleeve during the test.

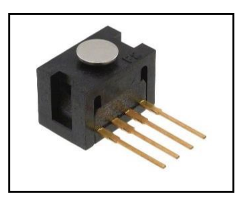

Figure 3. Force sensor [7].

The force sensor chosen is based on a Wheatstone bridge; by applying a force on the plunger of the sensor it will cause a symmetrical variation, however opposite, in the sensor outputs; as various forces represent variations of different voltage, it has a fundamental tension force ratio to determine the force applied. As a result of the information requested from the manufacturer along with this sensor, we also acquired an instrumentation amplifier (IA) [8, 9], with the reference INA122 from Texas Instruments [10].

The controller used was the Arduino UNO platform since the company already had one and it also can meet all the requirements necessary for the development of this project. With this controller it was possible to power up the circuit chosen.

To control the speed and direction of the DC motor, we used an Arduino module of the H bridge, as it allows to control both directions of the motor rotation. The module used is based on the IC L298 from ST, which is a dual H bridge [11]. The motor speed can be regulated through PWM (Pulse Width Modulation) being able to rotate at different speeds allowing faster/slower testing times. However, in order to get proper results, once the sleeve approaches the sensor, the motor speed should be as slow as possible, and in this case the possible slowest speed is manifested by the PWM value of 40, on a scale from 0 to 255. PWM values lower than 40 aren't enough to keep the motor in motion.

For position switches, we considered some roller switches as they are very affordable and of great efficiency.

Figure 4 presents the sensor output circuit designed [12, 13].

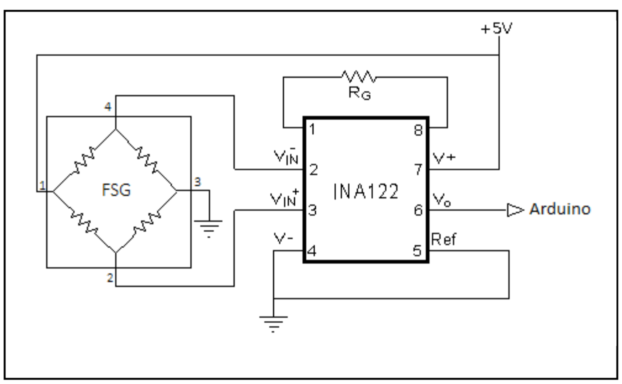

Figure 4. Circuit designed to read the sensor output.

Outlined the circuit, it was essential to scale the value of R_G (Fig. 4) being the gain (G) of the IA, $G = 5 + (200k/R_G)$. Since the circuit is powered from a 5V source it has to be ensured that the output does not exceed the 5V to force values up to 2.2 N, as it is the value of the maximum force applied to the spring of the sleeve. So, to calculate the gain, we defined as maximum value, hypothetically, applied to a weight of 308.8 g corresponding to an output of 0.038 V. For a maximum voltage of 4.8V, as a precaution, $G = 4.80/0.038 = 124$. Then, $R_G = 200k/(124-5) = 1.6k\Omega$.

In order to read the values from the sensor, we developed an application with the Arduino interface software (Fig. 5). The input considers an analogue port from the Arduino and depending on the ratio between the maximum and minimum values read there is a direct correspondence to the maximum and minimum values of the applied force value, respectively. Moreover, it is possible to make the mapping of values to get the current value of the force. This is only possible because the sensor features a linear behaviour.

So, verifying the minimum weight and the maximum weight that the Arduino can read, a relationship was established between the weight applied and the output voltage. Knowing the weight being applied, easily, it is then converted to Newton, multiplying it by 9.8 m/s^2 (acceleration due to gravity on Earth).

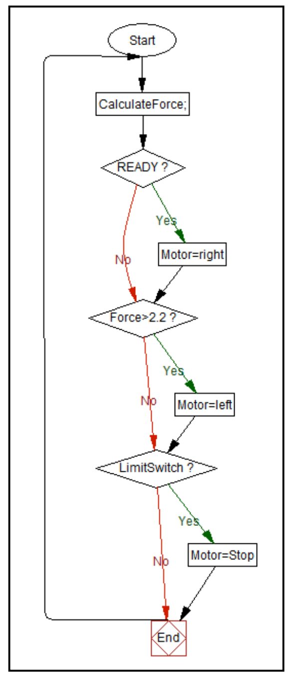

Figure 5. Flowchart of the Arduino interface code.

Following the flowchart (Fig. 5), the first step is to calculate the force in Newton; then if the operator chooses to begin the test, the motor will spin to the right, which means the sleeve will start to approach the sensor, if not, the motor does not spin.

Up next, if the applied force is higher than 2.2N, the motor will reverse its rotation, if not, the motor will keep his current configuration whether is stopped or is on the move.

If the limit switch is activated, it means that the sleeve is coming back, so the motor must stop, otherwise, the motor keeps the current configuration.

For security reasons, we implemented an emergency switch. This is a way to ensure control of the system, as once activated cuts off the system power. This switch should only be activated if the sleeve, for some reason,

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mechanical or by software, overload the sensor and reaches the switch.

If there were no security system implemented, certainly the mechanical components could be damaged.

The source code represented by the flowchart is executed every 5ms which represents a frequency of 200Hz, corresponding to a sensor output reading almost continuously, which allows to make nearly live decisions.

Once the Arduino code was completed, the code was implemented in C# programming language [14, 15], with the purpose of creating a user friendly interface that shows graphically the applied force value to the segment, transmitted through the application on Arduino.

It was imperative to establish a communication between the Arduino and the application [16]. With this purpose it was necessary to receive and send data through the serial port of the computer.

As this application uses several distinct features such as establish a connection by serial port or define a graph on the interface, it is essential to use delegate methods it allows updating the UI (user interface) thread, for getting or setting data.

To set the chart it was established that the Y-axis will represent the values of the force in mN and the X-axis will represent time in ms.

The chosen chart type is a line chart. For better perception of the maximum peak, a label is displayed in the interface with this information, as well as in any place of the chart it is displayed a tooltip with the coordinates.

Additionally, some other features were implemented in the application (Fig. 6), that result from the need to explore new concepts and offer different and contemplative solutions to the operator, such as the possibility of saving the chart to a file in JPG format, creation of a database (DB) [17] to store information regarding tests performed, or to print data and display it in a HTML page [18].

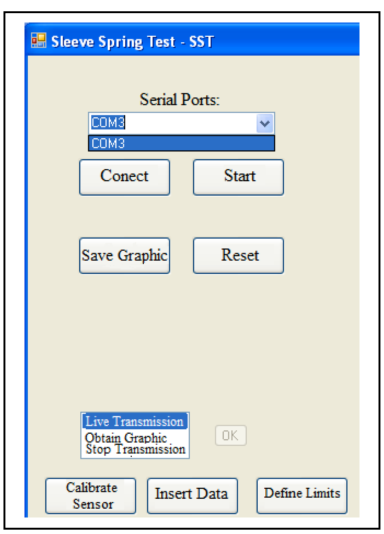

Figure 6. User interface.

B. Hardware Implementation

It was known beforehand that the device to develop should be robust. The idea was to create a system with a strap to allow the sleeve to move in the horizontal plane (Fig.7).

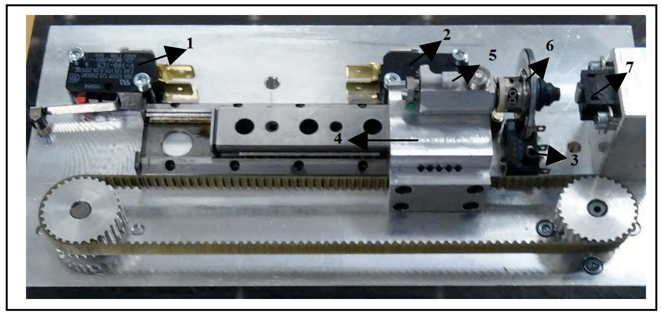

Figure 7. Motion system [1- position switch; 2- motor speed limit switch; 3- emergency switch; 4- movable part; 5-mechanical shirt; 6- sleeve/segment; 7- force sensor.]

Observing Fig. 7, the motor is connected to a pulley and, through a strap, this is linked to another pulley as well, as the movable part that carries the sleeve is attached to the belt, this will move horizontally. To give mobility to the movable part, this is attached to a bearing system, so when the belt moves, the movable part follows this movement. To put the sleeve to test in the movable part it was used a mechanical shirt that is permanently affixed to the movable part, so any sleeve can be tested as long as it is embedded in the mechanical shirt.

The electronic circuit was welded into a board allowing that all the components stay inside of the structure, thus protected from external disturbances.

The structure must guarantee that the test conditions are the same for all segments to be tested.

III. Final Tests and Installation

Once the software and the hardware were completed, the testing phase was undertaken. At first two sleeves were tested, one in a good state and another in a bad state, previously tested through the manual system. The results were very positive because we found large differences in the graphs obtained, so then only sleeves in good condition were tested for being able to establish parameters that identify the state of any sleeve (Fig. 8).

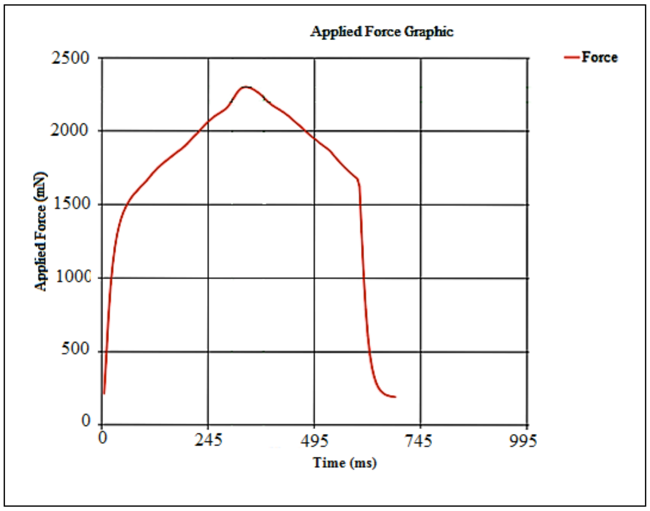

Figure 8. Sleeve in good condition.

On the basis of these tests, it was managed to check that if all the graphics of sleeves that show up in conditions of being used, approach the symmetry between the range 650ms and 800ms and the maximum number of force applied may not exceed the 2200mN.

By testing different sleeve states, we also verified distinct characteristics for each spring condition. Figures 9 and 10 are examples of graphs that represent the state of a loose spring (Fig. 9) and a stuck spring (Fig. 10).

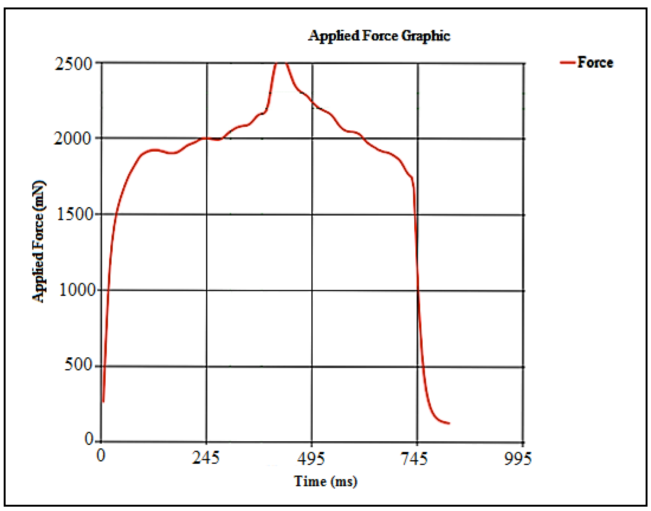

Figure 9. Sleeve with a loose spring.

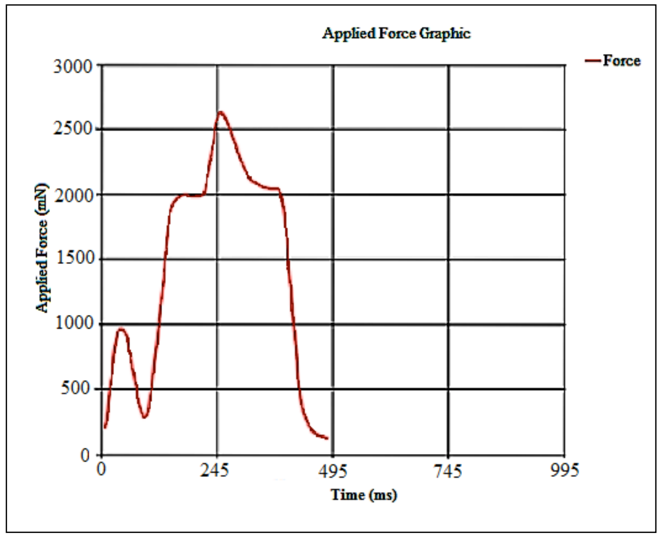

Figure 10. Sleeve with a stuck spring.

A loose spring does not offer as much resistance as a normal one so it takes longer time to achieve the maximum force. Moreover, when a stuck spring is tested the opposite is verified because the sensor captures the oscillations that a spring of this type causes - several peaks may result.

We performed several tests with segments in which it was previously knew the condition of them for validation. Afterwards, the device has been put to the test, and were carried out tests to about 50 segments, in which their condition was unknown. The application was able to successfully distinguish the sleeves that were ready to be used from sleeves that were in bad condition. Moreover, these results were later verified by the manual process and the results matched.

Furthermore, we implemented a functionality that allows to calibrate the sensor over time. The calibration procedure is accomplished by the same way as the method that is used to calculate the force, in other words is based on known masses. The relationship between the weight applied and the output voltage is recalculated given the new weights.

This calibration option is available, as seen, in the interface application and it is protected by password for security reasons.

The calibration, as previously referred, is performed using two weights, both of known masses, one which represents the minimum value and the other the maximum value. For that, simply it puts the weight on the sensor and depending on the value that the Arduino is receiving, a high or low value, it is regarded as a new value for the calculation of the force.

IV. CONCLUSION AND FUTURE WORK

This paper presents the development of a mechanical sleeve diagnosis system through a force sensor. The defined objectives for this project were achieved. Concerning the hardware, two weights, both of known masses all the test conditions to the sleeve. Regarding the software, we created a user interface for interaction with the operator in order to control and analyse the measures as well as represent them graphically, a DB was created for organization and storage of data. Additionally, it was implemented a sensor recalibration option as well as a function to define limits for analysis of the measures.

Based on the presented results and on the feedback from the operators, this new device shall allow the optimization of the performance and efficiency of the manufacturing unit. The developed product will have a great utility for the company in the way that it presents clear advantages compared with their previous manual method, among others, it saves time, enables better decision-making ability on the realized test, increasing the overall efficacy.

Furthermore, there are some ideas for future development, namely, to improve the user interface and to make the decision process of the sleeve state autonomous.

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