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Presentation of the content

In the first article we present, *Ultrasonic detector for predictive maintenance* by DUARTE-LOERA, Jorge, REYNOSO-JARDÓN, Elva Lilia, DÍAZ-RIVERA, Abelardo and ARÁMBULA-LEDEZMA, David Daniel with adscription in the Universidad Tecnológica de Chihuahua, in the next article we present *Spur gear manufacturing using conventional machine tools* by DELGADO-HERNANDEZ, Alberto, GONZALEZ-VIZCARRA, Benjamín, SIQUEIROS-HERNANDEZ, Miriam and AVILA-PUC, Miguel Ángel with adscription in the Universidad Autónoma de Baja California, in the next article we present *Didactic prototype of a robotic manufacturing cell to program welding trajectories in a frame* by MANDUJANO-NAVA, Arturo, PAZ-CABRERA, Mauro, SERRANO-RAMIREZ, Tomás and CHIHUAQUE-ALCANTAR, Jesús with adscription in the Universidad Politécnica de Guanajuato, in the last article we present, *Design and construction of pressure leak testers through the analysis of the filling level for the detection of defects in the nozzle of plastic containers* by MENDOZA-OLIVARES, José David, MARTÍNEZ-CARRILLO, Irma, JUÁREZ-TOLEDO, Carlos and BAROCIO-ESPEJO, Emilio with adscription in the Universidad Autónoma del Estado de México and Universidad Autónoma de Guadalajara.

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Ultrasonic detector for predictive maintenance

Detector ultrasónico para el mantenimiento predictivo

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Abstract

In the industry it is very common for failures to occur in machinery and equipment such as poorly lubricated elements; friction between mechanical elements; gas or vacuum leaks in pressurized systems; and electric arcs in motors, transformers and electrical installations. Each of these faults emits ultrasound and can be detected early using an ultrasonic detector. The objective of this work is to present a proposal for the development of a system capable of opportunely detecting the ultrasound emitted by faults, which is very useful for predictive maintenance. The methodology consists of the development of a system that detects the ultrasound decibels emitted by the fault using an ultrasonic sensor of the last generation, and the necessary interfaces. Ultrasound decibels will increase exponentially in the presence of these flaws, allowing their detection. This document offers an alternative for the development of an ultrasonic system useful in predictive maintenance, which is within the reach of any company.

Predictive maintenance, Ultrasonic sensor, Ultrasonic detector

Resumen

En la industria es muy común que se presenten fallas en las maquinarias y equipos como elementos mal lubricados; fricción entre elementos mecánicos; fugas de gases o de vacío en sistemas presurizados; y arcos eléctricos en motores, transformadores e instalaciones eléctricas. Cada una de estas fallas emite ultrasonido y pueden ser detectadas oportunamente utilizando un detector ultrasónico. El objetivo de este trabajo es presentar una propuesta para el desarrollo de un sistema capaz de detectar oportunamente el ultrasonido que emiten las fallas, el cual es de gran utilidad para el mantenimiento predictivo. La metodología consiste en el desarrollo de un sistema que detecte los decibeles de ultrasonido que emite la falla utilizando un sensor ultrasónico de última generación y las interfaces necesarias. Los decibeles de ultrasonido se incrementarán exponencialmente en presencia de estas fallas, lo cual permite su detección. Este documento ofrece una alternativa para el desarrollo de un sistema ultrasónico útil en el mantenimiento predictivo, que esté al alcance de cualquier empresa.

Mantenimiento predictivo, Sensor ultrasónico, Detector ultrasónico

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Introduction

Ultrasound is defined as sound waves with frequencies higher than 20 KHz which are outside the audible range for human beings, and that in order to be perceived, the inaudible sound must be transformed into frequencies that can be heard. It should be noted that the useful equipment to make this change is the ultrasonic detector for predictive maintenance (Ortega, 2004; Martinez, 2006). The basis of the operation of ultrasonic detectors is that when a fault occurs, very high frequency sound waves known as ultrasound are generated. By scanning the test area with an ultrasonic meter, the fault can be heard through the headphones as a flow sound which can also be observed on the display/decibel meter.

The closer the sensor is to the fault, the louder the flow sound and the higher the decibel reading. Ambient noise can be a problem, where a rubber focusing probe is normally used, in order to reduce the instruments receiving field and to protect against conflicting ultrasound. Also, frequency tuning drastically reduces background noise interference to facilitate more efficient ultrasonic detection (Realibity Web.Com, 2020). These detectors are part of the so-called non-destructive testing and allow the detection of faults in multiple systems and mechanisms in an early manner, relative to the detection done with vibration analysis.

It should be noted that the detection of incipient faults allows the programming of corrective actions without affecting production, without downtime and providing for the supply of spare parts in a timely manner. The faults that can be detected with this technology are poorly lubricated or defective bearings; detection of leaks in piping systems pressurised by any type of gas or vacuum; friction between mechanical elements; detection of electric arcs in motors, electrical installations and transformers.

The aforementioned breakdowns are common in industry and can be diagnosed in a timely manner if the company has this equipment, but due to its high cost it is not within the reach of companies with few resources. The aim of this work is to show an alternative for the development of an ultrasonic detector for predictive maintenance that is within the reach of any company.

Development

1. Industrial maintenance

It is a field of engineering of great interest and with a wide economic impact, as justified by the fact that in industrial societies, maintenance costs constitute an appreciable percentage of their gross domestic product. In some sectors, maintenance is essential for the development of the activity to which it is applied, while in others, the existence of effective maintenance is one of the most important elements for achieving competitiveness in the global economic framework (González, 2010). Industrial maintenance is defined as the set of activities aimed at guaranteeing the correct operation of the machines and installations that make up a production process, allowing it to reach its maximum performance.

The general objective of industrial maintenance is to plan, schedule and control all the activities aimed at guaranteeing the correct operation of the equipment used in production processes. Good maintenance scheduling provides companies with the following advantages: production of high quality products at low cost; customer satisfaction with regard to the delivery of the product in the agreed time; reduction of risks in work accidents caused by the poor condition of the machines or their components; reduction of costs caused by production process stoppages when unforeseen repairs occur; detection of faults caused by the wear and tear of parts allowing an adequate programming in the replacement or repair of the same; prevents irreparable damage to the machines; facilitates the preparation of the budget according to the needs of the company.

When companies do not have well-planned maintenance, losses can occur due to the following problems: Production process stoppages; unexpected equipment breakdowns, damage to raw materials; production of defective products; non-compliance with product delivery times; and accidents at work (Olarte, 2010). The main types of industrial maintenance that exist are corrective maintenance, preventive maintenance, predictive maintenance and reliability-based maintenance (González, 2010).

2. Predictive maintenance

The increase in automation meant that every failure that occurred had a more serious impact on productivity and product quality standards, in addition to the serious consequences it had on safety and the environment, at a time when the demands in these areas were growing rapidly. The inspection techniques developed in the decade by vibration analysis methods, ultrasound analysis, infrared thermography and other intensive and systematic inspection techniques, which were based on the prediction of failure before it occurred, following the behaviour through the monitoring of the condition of the equipment, in previously established time intervals, came into action. Maintenance that uses tools and techniques for measuring physical parameters to inspect equipment at regular intervals, taking action to prevent failures before they occur, is called Predictive Maintenance (Moubray, J. 2001).

Predictive maintenance consists of a series of non-destructive tests aimed at monitoring the operation of equipment to detect warning signs that indicate that some of its parts are not working properly. Through this type of maintenance, once faults have been detected, the corresponding repairs can be programmed in a timely manner without affecting the production process and thus prolonging the useful life of the machines. The techniques most commonly used in industry for industrial maintenance are vibration analysis, infrared thermography, ultrasound analysis and oil analysis (Olarte, 2010).

3. Types of predictive maintenance

3.1. Vibration analysis

This is the study of the operation of rotating machines through the behaviour of their vibrations. All machines present certain vibration levels even when they are operating correctly; however, when an anomaly occurs, these normal vibration levels are altered, indicating the need for an overhaul of the equipment. For this method to be valid, it is essential to know certain data about the machine such as: its rotation speed, the type of bearings, belts, the number of blades, blades, etc.

It is also very important to determine the points on the machines where the measurements will be taken and the most suitable analysing equipment for carrying out the study. With vibration analysis it is possible to detect faults in machinery and equipment such as: detecting friction in rotating machines; detecting faults and/or leaks in valves; detecting leaks in fluids; detecting vacuum losses; detecting electric arcs; verifying the integrity of seals in sealed enclosures.

The Vibration Analyser, as can be seen in Figure 1, is a specialised equipment that displays on its screen the vibration spectrum and the measurement of some of its parameters (Olarte, 2010). This technique is used to identify and predict mechanical anomalies in industrial machinery by measuring the vibration and identifying the frequencies involved. These vibrations are recorded by one or several accelerometers and the data are processed by a spectrum analyser.

The application of this technique in predictive maintenance greatly improves the efficiency and reliability of industrial machinery. Vibration analysis does not require disassembling or stopping the machine and is therefore a non-invasive method. In fact, a sensor that transforms motion into an electrical signal is the principle of a vibration analyser. Secondly, the analyser calculates all predefined parameters and then stores this signal (ERBESSD INTRUMENT, 2022).

Figure 1 Vibration analyser
Source: (Motionics, 2022)

3.2. Infrared thermography

Infrared thermography is a modern technology that uses cameras to measure and image the infrared radiation emitted by bodies without the need for visible light. As this radiation is a function of the body's surface temperature, the camera allows the calculation and visualisation of the body's surface temperature.

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In recent years it has become a key and affordable technology with multiple applications in numerous professional fields. It is being used from energy efficiency diagnostics in industrial and building installations, to medical diagnostics, research, art and security (Pérez, 2016). It is a technique that studies the temperature behaviour of machines in order to determine whether they are operating correctly. The energy that machines emit from their surface travels in the form of electromagnetic waves at the speed of light; this energy is directly proportional to their temperature, which implies that the greater the heat, the greater the amount of energy emitted.

Because these waves are longer than the human eye can see, it is necessary to use an instrument that transforms this energy into a visible spectrum in order to observe and analyse the distribution of this energy. Figure 2 shows the instrument used to generate an image of infrared radiation from the surface temperature of the machines, which is called a Thermographic Camera (Olarte, 2010).

Figure 2 Thermal imaging camera
Source: (Fluke, 2022)

Thermal imaging has developed into an indispensable aid in the maintenance of buildings and technical installations. Invisible infrared radiation not only makes it possible to monitor the function and condition of electrical and mechanical installations safely, but also to detect weak points and wear and tear in a timely and non-destructive manner, enabling timely solutions to be found. In addition, thermography provides services for quality control and fill level measurement of technical production facilities.

For example, system management enables perfect control of heating systems as well as simple and safe inspection of electrical systems (Testo, 2019).

3.3. Oil analysis

Oil analysis is one of the most important tools for preventive maintenance and allows quick and accurate laboratory evaluations of the lubricant used in equipment. With oil analysis, it is possible to detect both wear on moving parts of equipment and the presence of contaminants. An accurate diagnosis from oil analysis allows the people responsible for the maintenance of your company's machines and equipment to identify more quickly and even anticipate possible errors, avoiding compromising service performance or product quality. By betting on oil analysis, companies have only benefits. The useful life of components is extended, thus reducing expenses with replacement materials, unnecessary oil changes and labour for unscheduled maintenance (ALS, 2022).

This technique determines the operating condition of machines by studying the physical and chemical properties of their lubricating oil. Oil is very important in machines because it protects them from wear, controls their temperature and removes impurities. When the oil presents high degrees of contamination and/or degradation, it does not fulfil these functions and the machine starts to fail. The oil analysis technique makes it possible to quantify the degree of contamination and/or degradation of the oil by means of a series of tests carried out in specialised laboratories on a sample taken from the machine when it is operating or when it has just stopped.

The degree of contamination of the oil is related to the presence of wear particles and foreign substances and is therefore a good indicator of the condition of the machine. The degree of degradation of the oil serves to determine its condition because it represents the loss of lubricating capacity caused by a change in the properties of the oil and its additives. The contamination in an oil sample is determined by the quantification of: metallic wear particles, fuel, water, carbonaceous and insoluble matter. The information from the physical and chemical tests of the oil allows to decide on the lubrication and maintenance plan of the machine (Olarte, 2010).

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3.4 Ultrasonic detection

It is a very useful technique in Predictive Maintenance because it is used to detect the exact place where some type of breakdown or fault is occurring. For this reason, this detection technique is currently used throughout industry in Predictive Maintenance in the equipment of production plants, taking advantage of the properties of sound waves. That is why the use of ultrasound in Predictive Maintenance is an important tool for the development of the industry. Because it makes it possible to detect and locate problems in equipment long before they cause interruptions that lead to large economic losses (IMG, 2020).

Ultrasound is defined as "Sound waves with frequencies above the human audible limit, or in excess of 20,000 cycles per second (Hertz)". Because of this, this inaudible sound must be transformed into frequencies or signals that we can detect. Ultrasonic detectors measure the ultrasonic decibels and convert them into audible frequencies that can be heard with headphones. On the principle that faults emit ultrasound, it is possible to detect them by measuring the decibels of ultrasound they emit, as the decibels of ultrasound detected will increase exponentially in their presence. By means of ultrasound detection and analysis it is possible to detect faults in: poorly lubricated or defective bearings; leaks in piping systems pressurised by any type of gas; leaks in vacuum systems; presence of electric arcs in motors, transformers and electrical installations.

This technique used in predictive maintenance, which is part of the so-called non-destructive testing, allows the detection of faults in multiple systems and mechanisms even earlier than, for example, vibration analysis. The detection of incipient failures allows the programming of corrective actions without affecting production, without downtime and providing for the supply of spare parts in time (Olarte, 2011; Díaz, 2019). Ultrasonic fault detection is an easy, fast and effective method in noisy environments. Ultrasound accurately locates those areas where there are incipient problems. All this allows the proper scheduling of predictive maintenance of equipment without hindering the normal development of the company.

It is important to know that all mechanical and electrical problems, as well as vacuum or pressure leaks, generate ultrasonic waves. These are detected by means of meters in order to locate the problem and take corrective action to solve it. So to detect ultrasound, an instrument called an ultrasonic detector is used, designed to capture ultrasonic waves and convert them into signals with frequencies within the range of human hearing. This device has the technology so that once converted, the waves can be heard through headphones or displayed on a screen. Figure 3 shows an ultrasonic detector via headphones, and Figure 4 shows one via a display.

Figure 3 Ultrasonic detector with earphones
Source: (Zamtzu, 2022)

Figure 4 Ultrasonic detector with display
Source: (Zamtzu, 2022)

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Ultrasonic detectors are easy to use equipment where the sound is directional. Thus, the operator can check any area by locating the source of the problem which manifests itself as a much louder sound than at other points. These detectors have a frequency selector that allows the operator to filter out ambient noise and hear the ultrasonic wave clearly. The internal design of an ultrasonic detector is shown in Figure 5 (Olarte, 2011; IMG, 2020).

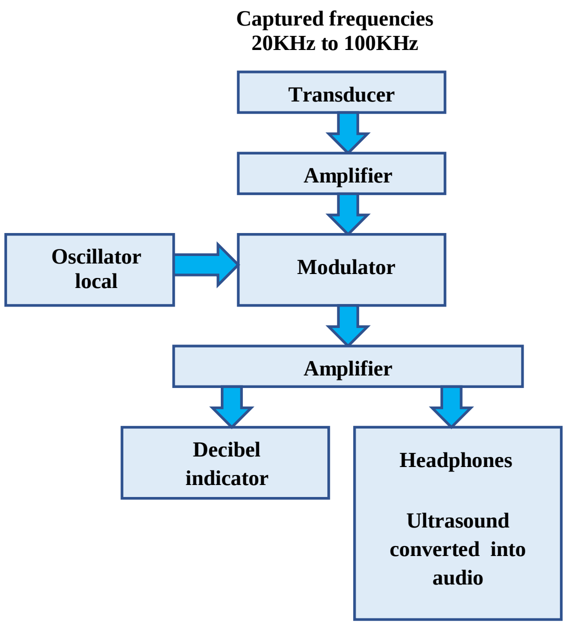

Figure 5 Internal design of an ultrasonic detector
Source: (Olarte & Botero, 2011; IMG, 2020)

4. Development of the Ultrasonic Detector

Figure 6 shows the block diagram of the ultrasonic detector.

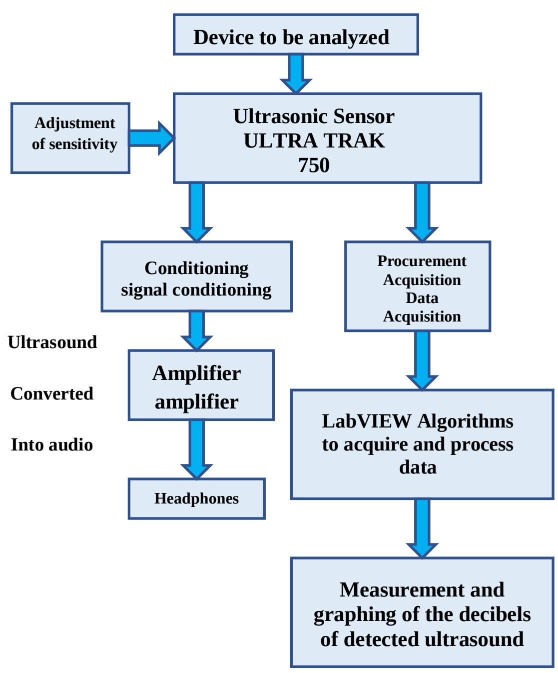

Figure 6 Block diagram of the ultrasonic detector
Source: (Diaz, 2019)

A ULTRA-TRAK 750 UE System sensor is attached to the mechanical system that is intended to sense the ultrasound it emits. This is a contact ultrasonic sensor and is shown in Figure 7.

Figure 7 Ultrasonic detector Ultra Trak 750
Source: (UESYSTEM, 2022)

The sensor has a current source proportional to the decibels of ultrasound detected, the operating range of this source fluctuates between 0 and 30 milli amperes (mA) and is proportional to the detected ultrasound peaks in decibels (dB). The output current is converted to voltage by passing it through a 249 Ω resistor. This voltage is proportional to the detected dB and is digitised by a National Instruments NI USB-6008 data acquisition board. The data is fed in real time to a laptop via a USB port. The laptop uses National Instrument's LabVIEW algorithms to acquire data; calculate the ultrasound dB; display and graph it all in real time. The transfer function of the sensor is shown in equation (1) and is used by the algorithms to calculate the ultrasound dB (UESYSTEM, 2022).

$$dB = 2.4403 I_s - 6.5144 \qquad (1)$$

Where dB is the detected ultrasound decibels and I_s is the output current in milliamps. The output current is converted to an output voltage by passing it through a 249 Ω resistor according to Ohm's law and is described by equation (2) (UESYSTEM, 2022).

$$V_s = 249000 I_s \qquad (2)$$

Where V_s is the output voltage proportional to the dB of detected ultrasound.

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The ULTRA-TRAK 750 sensor internally converts the detected ultrasound into an audible frequency by heterodyning. The audio is conditioned by a pre-amplifier and a low-pass filter, then amplified in power and channelled to headphones. There are therefore two indicators that ultrasound is detected, the decibel graphs on the laptop and the audio present in the headphones. The ULTRA-TRAK 750 sensor also has two internal lines for adjusting the sensitivity of the sensor, one line can be adjusted manually and the other line can be adjusted from the laptop using an algorithm. Figure 8 shows the prototype of the ultrasonic detector.

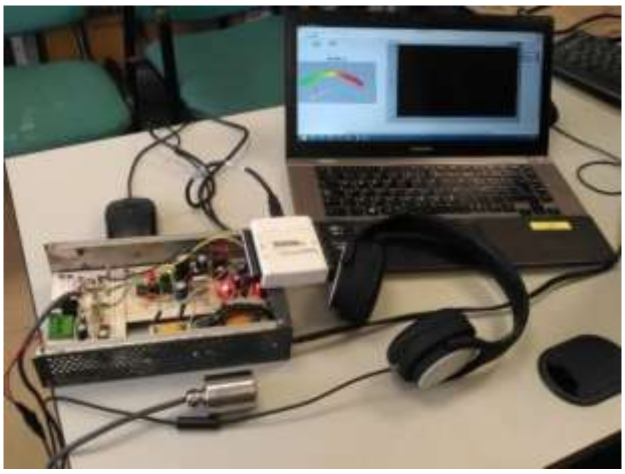

Figure 8 Prototype of the ultrasonic detector

Figure 9 shows the front panel of the LabView algorithms developed by measuring and plotting the ultrasound.

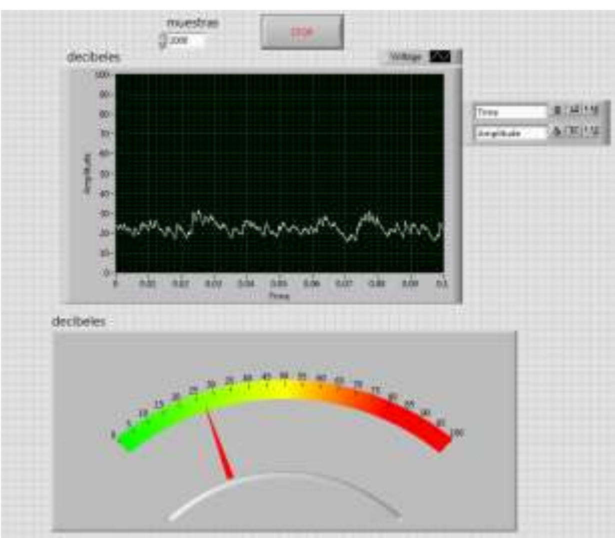

Figure 9 Front panel displaying and graphing dB of ultrasound

5. Results

A pipig system to which a vacuum pressure of 25 inches of mercury is applied was fabricated as a test platform to validate the effectiveness of the ultrasonic detector. The test platform is shown in Figure 10.

Figure 10 Vacuum leakage test platform
Source: (Diaz, 2019)

Several vacuum leakage points are intentionally placed in the initially hermetic system. Table 1 shows the behaviour of the measured ultrasound dB readings in the system with the developed ultrasonic detector in the presence of a leak.

Position	dB ultrasound
At the point of leakage	40
5 cm from the leak	15
10 cm from the leak	12
20 cm from the leak	10
30 cm from the leak	8
At 40 cm from the leak	5
At 50 cm of the leakage	5
At 60 cm of the leakage	5
At 100 cm from the leakage	5

Table 1 Ultrasonic decibels measured at different distances from a vacuum leak using the developed ultrasonic detector

The detector shows small ultrasonic dB readings in the leak-free pipe sections, and little flow noise in the headphones. These readings are due to ambient noise. In the presence of a leak, the measured dB increases exponentially with increasing flow noise in the headphones. Each leak is located by the ultrasonic detector.

Measurements are also carried out on bearings operating in a hydraulic pump. The bearings are known to be in good condition. The dB measurements are small (5 dB) due to the ambient noise as well as the flow noise in the headphones. The same operation is performed but now the bearings are known to be in bad condition. The dB measurements are high (35 dB), as well as the flow noise in the hearing aids. It is observed that the ultrasonic detector discerns between good bearings and those that are defective or poorly lubricated.

6. Conclusions

From the validation of the ultrasonic detector through the tests carried out, it is clear that it performs well, which makes it valuable for use in predictive maintenance. In addition, it can also be used by schools in laboratory practices related to non-destructive testing. The developed system is low cost which makes it accessible to companies with few resources but mainly to educational institutions.

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Spur gear manufacturing using conventional machine tools

Manufactura de engrane recto utilizando maquinas herramientas convencionales

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Abstract

The objective of this writing is to develop a methodology for the manufacture of a spur gear prototype using conventional machine tools. The purpose of this article is to help scientists and engineering students who need a guide to manufacture this type of elements that are part of a mechanical system for the transmission of movement and force. This study intends a comprehensive analysis of each step used for the manufacture of a spur gear, which allows in an objective way to determine the cutting tools and equipment necessary to carry out its manufacture, starting from the design of the element in question and applying the technical formulas necessary to adjust the parameters in the machining of the part. The methodological approach for this study has been determined based on the practical skills and experience that are paramount in the use of conventional machines. As a contribution we can say that with this methodology it will be possible to eliminate many previous problems in terms of planning and the lack of experience in handling conventional tools.

Spur gear, Manufacturing, Conventional machines

Resumen

El objetivo de esta escrito es desarrollar una metodología para la manufactura de un prototipo de engrane recto mediante el uso de máquinas herramientas convencionales. El propósito de este artículo es ayudar a científicos y estudiantes de ingeniería que necesitan una guía para manufacturar este tipo de elementos que forman parte de un sistema mecánico para la transmisión del movimiento y fuerza. Este estudio pretende un análisis comprensivo de cada paso utilizado para la fabricación de un engrane recto, que permita de manera objetiva determinar las herramientas de corte y equipos necesarios para llevar a cabo su manufactura, partiendo del diseño del elemento en cuestión y aplicando las fórmulas técnicas necesarias para ajustar los parámetros en el maquinado de la pieza. El enfoque metodológico para este estudio se ha determinado en base a las habilidades prácticas y experiencia que son primordiales en el uso de máquinas convencionales. Como contribución podemos decir que con esta metodología se podrán eliminar muchos problemas previos en cuanto a la planeación y la falta de experiencia en el manejo de herramientas convencionales.

Engrane recto, Manufacturar, Maquinas convencionales

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Introduction

Gears are extremely common components used in many machines. In general, the function of a gear is to transmit motion from one rotating shaft to another. In addition to transmitting motion, gears are often used to increase or decrease speed, or to change the direction of motion from one shaft to another.

They are extremely common in the output of mechanical power sources, such as electric motors and internal combustion engines, which rotate at much higher speeds than the application requires.

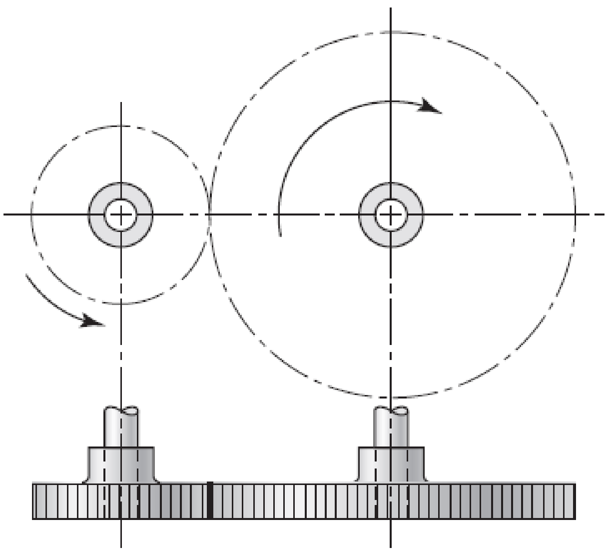

Figure 1 Spur gear

Spur gears are used to transmit rotational motion between parallel axes as shown in Figure 1 (Shigley's mechanical engineering design, 2011).

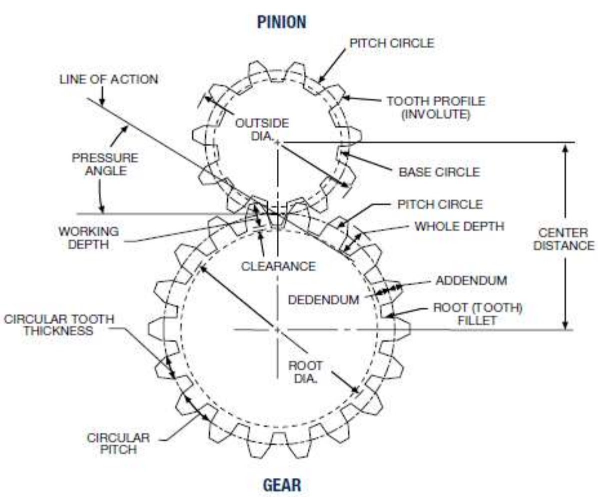

Figure 2 Parts of a spur gear

Although there are currently various techniques for manufacturing gears on a large scale, it is still important to manufacture them using conventional machine tools, which bring into play the skills and abilities in the training of engineers, which will facilitate their entry into the professional world.

In this case, a prototype of a spur gear is manufactured by identifying its main parts in Figure 2 (Edward G. Hoffman, 2006) and using a cutter as shown in Figure 3.

Figure 3 Spur gear cutter

The most important data we need to take into account for the manufacture of a spur gear are: Diametral Pitch (DP), Cutter Number (#8), Number of gear teeth that can be manufactured using this cutter (12 to 13 teeth), and the pressure angle which is 14.5o. This information is printed on the surface of the cutter Figure 3.

Tooth range	Cutter number
134 - greater	1
55 - 134	2
35 - 54	3
26 – 34	4
21 – 25	5
17 – 20	6
14 – 16	7
12 - 13	8

Table 1 Tooth range for each cutter number

Table 1 presents each cutter number with its respective range of gear teeth that can be made, so depending on the number of teeth that need to be manufactured we choose the cutter number.

Diametral Pitch	Circular Pitch	Thickness of tooth on Pitch Line	Depth to be Cut in Gear	Addendum
3	1.0472	.5236	.7190	.3333
4	.7854	.3927	.5393	.2500
5	.6283	.3142	.4314	.200
6	.5236	.2618	.3565	.1667
8	.3927	.1963	.2696	.1250
10	.3142	.1571	.2157	.1000
12	.2618	.1309	.1798	.0833
16	.1963	.0982	.1348	.0625
20	.1571	.0785	.1120	.0500
24	.1309	.0654	.0937	.0417
32	.0982	.0491	.0708	.0312
48	.0654	.0327	.0478	.0208
64	.0491	.0245	.0364	.0156

Table 2 Standard diametral pitches for spur gears

Table 2 shows the standardised Diametral Pitch values with their respective values that define the geometry of the gearing using the diametral pitch system. Taking into account that the diametral pitch in a gear is the number of teeth per inch of the pitch circle, see figure 2.

The lack of a methodology for manufacturing spur gears has remained a problem in the formative stages of the engineering stage. This project highlights the importance of explaining in detail the steps involved in manufacturing a spur gear using conventional machines.

Methodology

The methodological approach adopted in the manufacture of this prototype spur gear is based on the characteristics required to be achieved and these are as follows:

To machine a spur gear with an outside diameter of 3.25" and having 24 teeth, as shown in Figure 4. First, a drawing was made using SolidWorks software, with the necessary technical parameters based on the ASA B6.1-1932 standard.

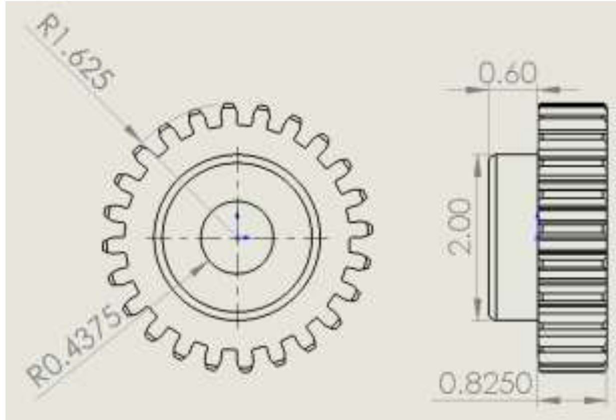

Figure 4 Spur gear dimensions

The values and formula used for the gear design are given in Table 3 and are based on the diametral pitch system (ERIK OBERG, 2016).

Variable	Value/equation	Result	Remarks
OD	3.25 in		Outsi of diameter
NT	24		Number of tooth
PA	14.5 deg		Pressure angle
PD	OD*NT/NT+2	3 in	Pitch diameter
DP	NT/PD	8	Diametral pitch
DB	PD*cos (PA)	2.9044 in	Base circle diam
WD	2.157/DP	0.2696 in	Whole depth
AD	PD/NT	0.125 in	Addendum
DD	1.157/DP	0.1446 in	Dedendum
CT	1.5708/DP	0.1963 in	Circular thickness
DR	PD-(2*DD)	2.7108	Root diameter
INV	0.125*PD	0.375 in	Involute radius
CTA	(360/NT) *0.5	7.5 deg	Circular thickness angle

Table 3 Technical characteristics of spur gears

Figure 5 Facing and roughing operations

After defining the dimensions, the first machining operations are carried out, in this case facing and roughing as well as drilling in 6061 aluminium material, using a carbide burin on a conventional lathe.

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Figure 6 Placing the part on the indexer

After what was done on the conventional lathe, the next step is to clamp the part on the table of the conventional milling machine using the indexing head with its respective counterpoint, it is worth mentioning that the alignment of the part with the spindle is very important, otherwise the teeth of the spur gear will be out of position.

Figure 7 Definition of the chuck on the indexer

To determine the chuck with the appropriate number of points for a 24-tooth gear, we use the following formula (Steve F. Krar, 2013).

$$X = V / T \tag{1}$$

Where:
X= Turns of the crank.
V= Ratio of the dividing head and the crank.
T= Number of divisions to be cut.

By means of the operations carried out, it is obtained that it is necessary to turn the indexer crank plus twelve points of the plate containing 18 points by one complete turn, this is done to cut the appropriate number of teeth based on the characteristics shown in Table 3.

Figure 7 shows the indexer chuck with a different number of points, allowing the workpiece to be rotated the appropriate degrees for cutting each gear tooth.

Figure 8 Cutting of each of the gear teeth

In order to continue with the manufacturing process, the cutting stage is carried out at depths of .090 in for each one of them until reaching 0.2696 in (Hole depth), as indicated in Table 3 and illustrated in Figure 8.

Results

Figure 9 shows the finished spur gear, where the teeth of the gear can be seen, it can also be seen that a chamfer cut was made on both sides of the tooth to remove the cutting edge of this, the cutting marks of the tool are present at the ends of the tooth.

Figure 9 Finished gear

Conclusions

To clearly explain the results obtained and the possibilities for improvement.

In this work we have proposed and explained the steps to follow in order to manufacture a spur gear using conventional machines and applying the technical formulas for its design, as the results show. It should be pointed out that practice and experience play a fundamental factor in the machining process, as well as the safety and skills of the person during the manipulation of the conventional lathe and milling machine.

Acknowledgement

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Didactic prototype of a robotic manufacturing cell to program welding trajectories in a frame

Prototipo didáctico de una celda de manufactura robotizada para programar trayectorias de soldadura en un chasis

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Abstract

This project shows the integration of a didactic prototype of a robotic manufacturing cell for the programming of welding trajectories in a chassis. The purpose of this project is to integrate the robotic cell through the interaction of the controller of an industrial robot, a programmable logic controller (PLC) and a power transmission system for the positioning of a chassis for didactic purposes for students studying engineering in the area of Industrial Automation. To carry out the project, a scale chassis for a tractor and its support base was first manufactured, then the control of a stepper motor was carried out through a SIMATIC S7-1200 CPU 1214C PLC and a microstep driver module. The programming software COSIMIR from FESTO was also used to program the welding trajectories in a Mitsubishi RV-2AJ robot with 5 degrees of freedom that interacts with the PLC through input and output digital modules. Finally, it was possible to obtain a functional prototype of a robotic manufacturing cell that can be used for teaching robot trajectory programming and that is closely related to industrial machines.

Didatic, Integration, Prototype

Resumen

En el presente proyecto se muestra la integración de un prototipo didáctico de una celda de manufactura robotizada para la programación de trayectorias de soldadura en un chasis. El propósito de este proyecto es integrar la celda robotizada a través de la interacción del controlador de un robot industrial, un controlador lógico programable (PLC) y un sistema de transmisión de potencia para el posicionamiento de un chasis con fines didácticos para los alumnos que cursan una ingeniería en el área de Automatización Industrial. Para realizar el proyecto primeramente se fabricó un chasis a escala para un tracto camión y su base de soporte, enseguida se realizó el control de un motor a pasos a través de un PLC SIMATIC S7-1200 CPU 1214C y un módulo microstep driver. También se utilizó el software de programación COSIMIR de FESTO para programar la trayectoria de la soldadura en un robot Mitsubishi RV-2AJ de 5 grados de libertad que interactúa con el PLC a través de sus módulos de entradas y salidas digitales. Finalmente se pudo obtener un prototipo funcional de una celda de manufactura robotizada que puede utilizarse para la enseñanza de programación de trayectorias de robots y que tiene una amplia cercanía con las máquinas industriales.

Didáctico, Integración, Prototipo

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Introduction

Currently in public institutions in Mexico, it is an important challenge to achieve significant learning in students, especially those who are currently studying engineering. Specifically in the state of Guanajuato in Mexico, large car assembly plants have been installed which brings with it increasingly complex production processes, so it is necessary to have trained personnel to meet the labour demands of this industrial sector and now with the new trends of industry 4.0, will bring major technological, social, economic and educational changes.

The automotive industry is a sector that is characterised by a high demand for skilled labour, which is why recently graduated engineering students who do not have work experience in the manufacturing industry find it difficult to adapt quickly to the labour sector due to their lack of professional experience or, what is more complicated, lack of opportunities to obtain their first job.

(Márquez and Pinargote, 2022), indicate that nowadays education in general requires a change in the teaching method, where the teacher must be willing to develop certain skills outside the context of the traditional curriculum, knowing the ways to implement holistic, active and practical teaching that best suits the day to day.

Consequently, it is necessary to develop didactic prototypes that contribute to the meaningful learning of students, (Diaz, Casachagua, Ortiz, Cuellar and Raymondi, 2022) mention that these prototypes are an alternative to the lack of equipment in workshops and/or teaching-learning laboratories in educational institutions of basic and higher education.

However, in basic industrial robot programming courses, the trajectories of the robot tool are generally programmed with different coordinate systems and some geometric figures are used as trajectories: circles, triangles, squares and curved lines to simulate the robot performing a specific task.

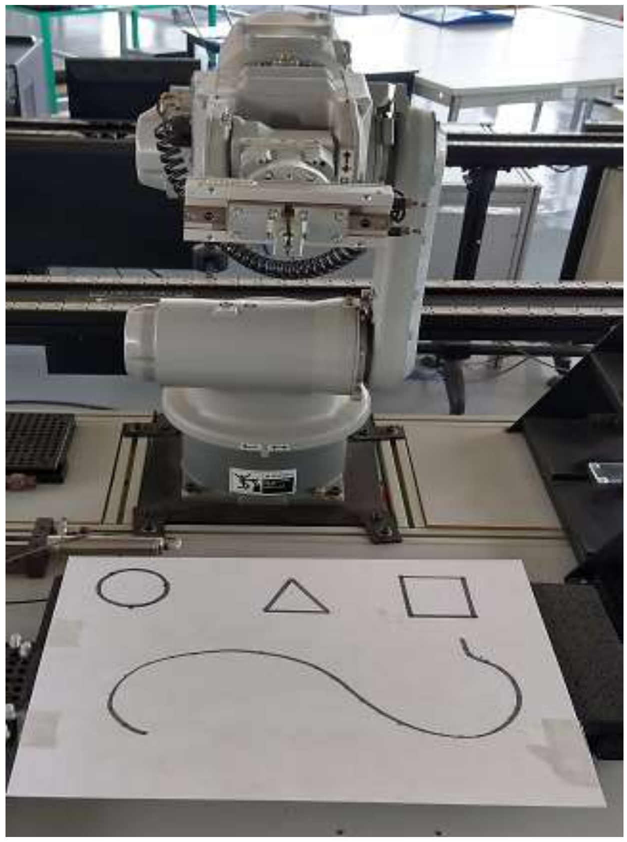

Figure 1 Trajectories of the robot with geometric figures
Own Authorship

Therefore, the students only learn to record points to generate a robot trajectory with geometric figures, but they do not understand the relationship that exists in an industrial process such as applying paint, welding or for making an assembly, so the programming logic is lost when faced with a real problem.

Problem statement

Based on the educational programs of the Automotive Engineering careers of the Polytechnic University of Guanajuato, it is proposed that several graduates will be working in the area of manufacturing processes and automation. With the development of this robotic cell, students from the Automotive Engineering areas will acquire skills for programming the trajectories of a robot in the welding process and will also understand the interaction between a PLC and the input and output modules of the controller of an industrial robot in a manufacturing cell. This will help graduates to adapt quickly to the demands of the labour sector based on Industry 4.0 in the future.

Cell integration

The robotic cell consists of a Mitsubishi RV-2AJ 5-degree-of-freedom robot with a 2 kg payload capacity, a SIMATIC S7-1200 CPU 1214C DC/DC/DC PLC, a power transmission system, a 1.8° stepper motor per step, a 9-42 VDC microstep driver module, a chassis for a scale built tract truck with its support, the COSIMIR programming software from FESTO for programming the robot trajectories and the TIA PORTAL V13 programming software for programming the PLC. Its principle of operation is based on a robotic cell controlled through a PLC and an industrial robot that has the ability to program the welding process trajectories on a chassis and through a power transmission system, the chassis is positioned as required by the process. In the following sections, the methodology followed for the realisation of the project is presented.

Design and manufacture of the chassis

Firstly, the model of a chassis for a tractor truck with its powertrain system was chosen; then the 3D modelling of each of the parts was started in SolidWorks 2019 software. Once we had the 3D model, we proceeded to manufacture the chassis components using a CNC machining centre and a 3D printer, which was used to manufacture some of the differential components.

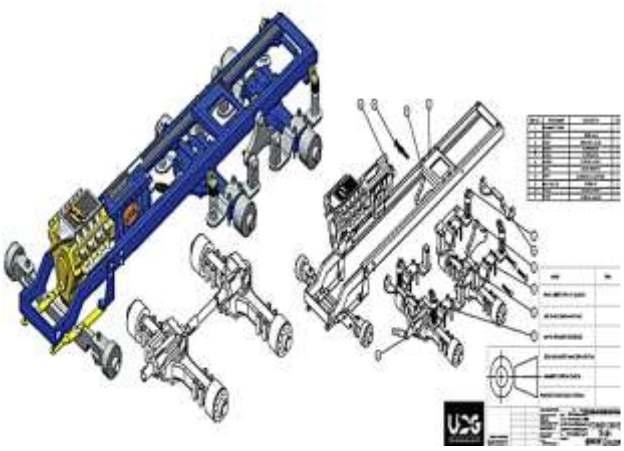

Figure 2 Virtual prototype of the chassis
Own Authorship

Once the chassis parts were fabricated, the final assembly was carried out. A frame was also required to act as a means of support for the chassis and the power transmission system.

Figure 3 Physical prototype of the chassis
Own Authorship

Power transmission system

The power transmission system consists of the stepper motor, a coupling, a speed reducer with a 20:1 ratio, a synchronous belt drive that helps to ensure synchrony between the stepper motor and the chassis, as well as preventing slippage between the belt and the pulleys. This system is used to rotate the chassis to the desired position so that the robot then follows the trajectories programmed in the welding application.

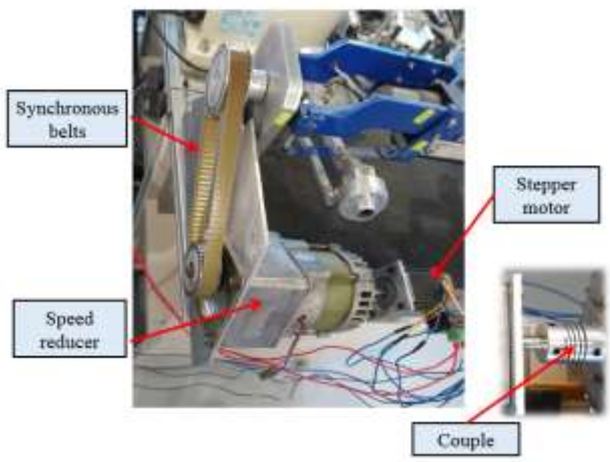

Figure 4 Power transmission system
Own Authorship

Stepper motor control with the PLC

A stepper motor with two 3A windings and a positioning accuracy of 1.8° per step was used to position the chassis. The stepper motor was controlled by a SIMATIC S7-1200 CPU 1214C DC/DC/DC PLC, a microstep driver module DC: 9-42 VDC, a 24 VDC 4A voltage supply, a pushbutton panel and the programming software TIA PORTAL V13. To start with the motor control, first the PLC characteristics were registered in the TIA PORTAL V13 program, then the hardware was programmed to activate the PTO/PWM fast pulse generator with PTO pulse A and B direction options.

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The PTO pulse A pulse is used to send pulses to the motor and the PTO output B direction is used to change the motor rotation.

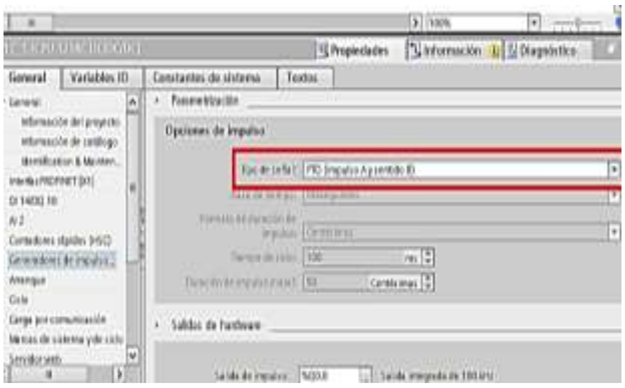

Figure 5 Activation of the PTO/PWM fast pulse generator
Own Authorship

As a next step, a positioning technology object was used within the PLC programming. In this technological object, a wizard is used to indicate the operating parameters of the stepper motor, such as: units, the type of control with PTO type pulse output, the number of pulses per revolution, the configuration of the limit switches and the configuration of the motor dynamics.

Figure 6 Stepper motor activation parameters
Own Authorship

Finally, to finish with the programming for the stepper motor control, an OB1 organisation block was used within the PLC project tree. This control was carried out in contact diagram (KOP) using the motion control programming tools. As a first stage of this project, two digital inputs were used to receive the chassis position signal via two inductive sensors, and two digital outputs were used to send signals to the robot to indicate the start of the trajectory programmed in the robot controller.

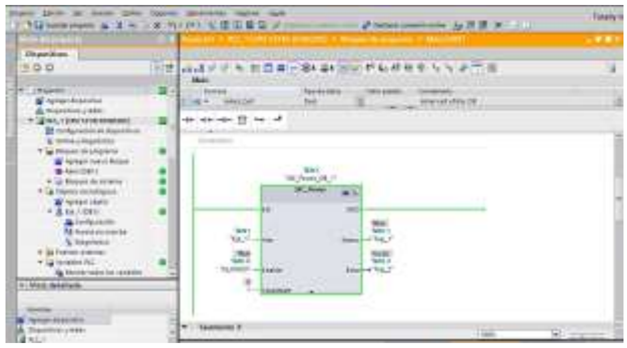

Figure 7 Stepper motor programming
Own Authorship

Stepper motor power stage with the Microstep Driver

As mentioned above, the motor used has two coils with an accuracy of 1.8° per step, so it requires 200 pulses to make a full 360° turn. To calculate the step angle, the following expression is used.

$$Angle\ of\ passage = \frac{360°}{(TH)\ x\ (FH)} \quad (1)$$

Where:
TH = Number of rotor teeth
FH = Number of phases

Therefore, the stepper motor used has a 50-tooth rotor and a 4-phase stator resulting in 1.8° for each pulse sent to the controller. To make the physical connections to the motor and Microstep Driver controller, it was first necessary to identify the control and power signals in the controller, as well as the number of motor steps per revolution. In this case, if 200 pulses are required for each revolution of the motor shaft, the controller switches were positioned based on the number of pulses required in the motor.

Figure 8 Programming of the Microstep Driver for stepper motor
Own *Authorship*

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To connect the power stage, the A+ A- B+ B- coils of the motor were connected to the power inputs of the Microstep controller. These connections were made as shown in the figure below.

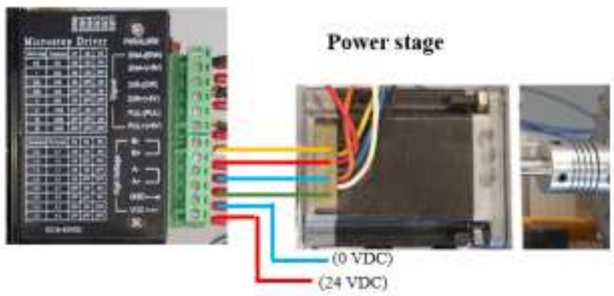

Figure 9 Stepper motor power stage
Own authorship.

Stepper Motor Control Stage with Microstep Driver and PLC

This stage requires connecting the pulse control outputs of the PLC to the control inputs of the Microstep Driver.

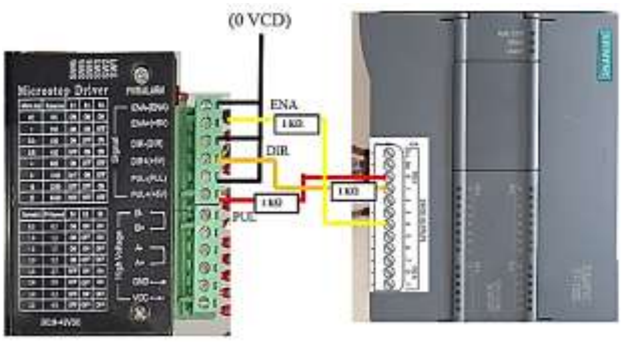

Figure 10 Stepper motor control stage
Own authorship.

To control the motor through the PLC, 4 outputs were used. Output Q0.0 (PUL) was used to send the pulses, output Q01 (DIR) to make the motor rotation change, output Q0.3 (ENA) to disable the motor when the control signal is not being sent, and output Q0.4 was used to send the cycle start signal to the robot.

In addition to the PLC outputs, 5 digital inputs were used. Input I0.0 was used to start the work cycle (STAR), input I0.1 was used to stop the work cycle (STOP), inputs I0.2 and I0.3 were used to connect the sensors that detect the position of the chassis and finally input I0.4 was used to receive the end of cycle signals from the robot.

Programming of the Mitsubishi RV-2AJ Robot with the COSIMIR platform of FESTO

The robot used in the project is an articulated robot Mitsubishi RV-2AJ of 5 degrees of freedom with a capacity to load 2 kg and a maximum radial reach of 460 mm, has a 64-bit CPU controller that allows parallel execution of up to 32 programs in multitasking mode, plus an interface module with 16 digital inputs and 16 digital outputs.

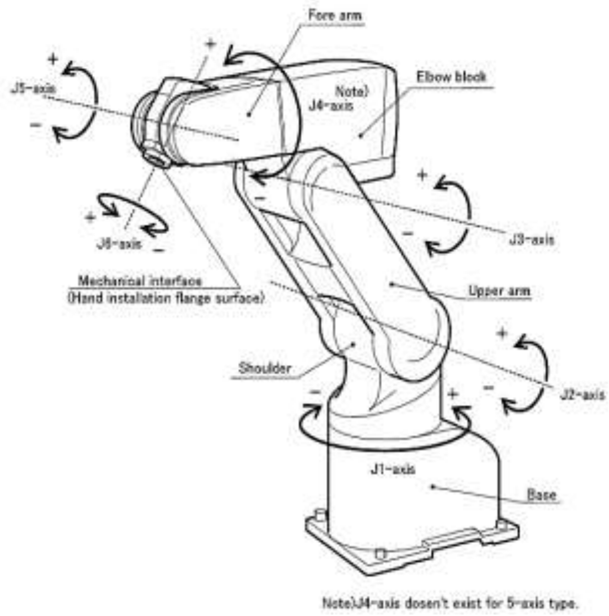

Figure 11 5-degree-of-freedom robot joints. Taken from Mitsubishi Industrial Robot RV-1A/RV-2AJ Series, Standard Specifications Manual (CR1-571 Controller (p. 2-10), Mitsubishi Electric Europe B.V. Germany, (2009).

The robot can be programmed through its teach pendant control panel or also with the COSIMIR programming software from FESTO, which is a graphic software based on the MELFA-BASIC-IV programming language that helps to easily program the trajectories to be carried out with the robot.

The communication interface between the robot controller and the computer is via an RS232 port, as well as a module with 16 digital inputs and outputs that help to communicate the robot with the outside world.

When creating a new project, 5 windows are opened.

1. Robot Observation window is used to observe the movements performed by the robot.

2. Programming window: in this window, the program codes are displayed.

3. Error Report Window: this window is used to check that there are no errors in the programming.

4. Model Scan Window: used to observe the programs loaded inside the Robot if the connection between the CP and the Robot has been established.

5. Positions window: this window is used to save the robot's Positions for later use in the programming window.

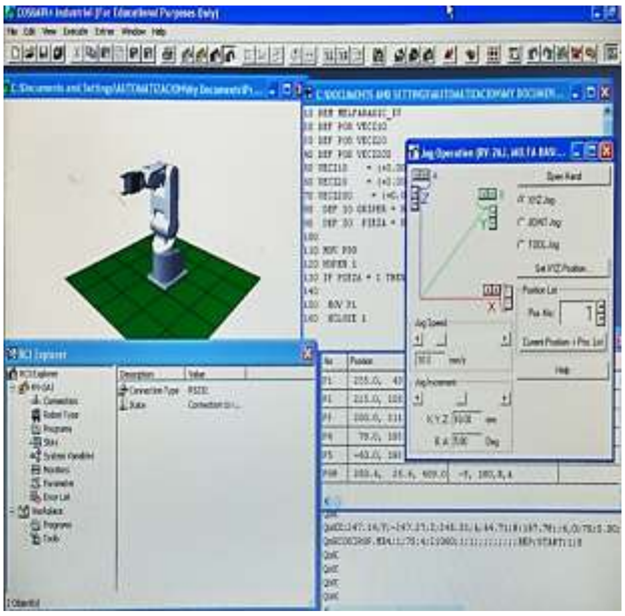

Figure 12 Programming of the robot trajectories
Own Authorship

To generate the programming of the robot trajectories, the Joint coordinates, Cartesian coordinates or tool coordinates of the robot are used to position the tool tip in the areas where the welding is to be applied. Then the points where welding is required are saved until a work cycle is generated. Finally, the robot input that receives the PLC signal to indicate the start of a work cycle once the power transmission system has positioned the chassis, and a digital output in the robot output module to send the signal that the work cycle has been completed, are registered.

Results

Based on the stages and the integration of the systems in the development of this project, such as the design and manufacture of the chassis, the stepper motor control system through the SIMATIC S7 1200 PLC and the Microstep Driver controller, the Mitsubishi RV-2AJ articulated robot with 5 degrees of freedom and the COSIMIR programming software from FESTO to programme the robot trajectories, it was possible to develop a functional prototype of the robot; a functional training prototype was developed for engineering students in the area of industrial automation, which has the capacity to simulate the trajectories of the welding process in a robotised cell where the student recognises the interaction for programming a PLC and the controller of an industrial robot as part of a hierarchy of the pyramid of industrial networks that are part of Industry 4. 0.

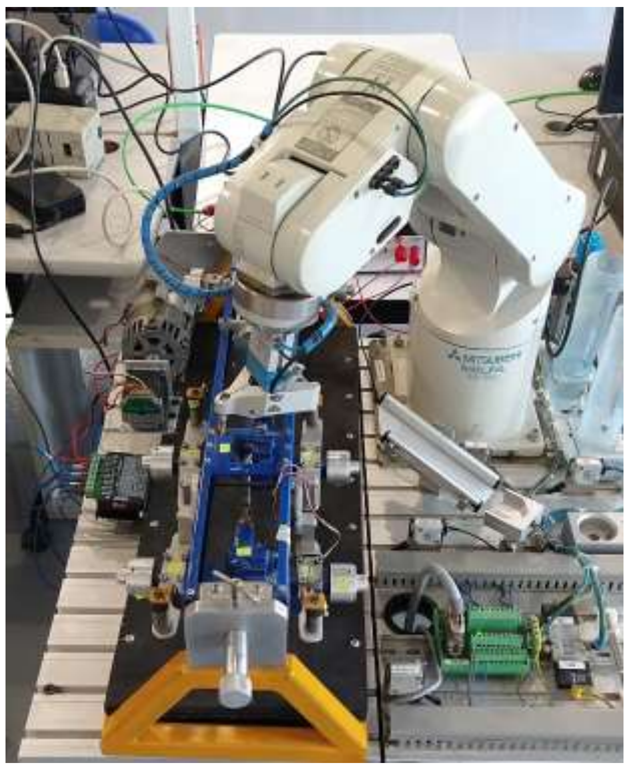

Figure 13 Final prototype of the robotic cell
Own Authorship

Conclusions

With the completion of this project, the initial objectives set at the beginning of the project were met, as a functional didactic prototype was integrated, which has some advantages compared to traditional ways of teaching robot trajectory programming, to mention a few:

– Programming of a logical sequence of trajectories of an industrial robot for work cycles in a welding process.

– Control of a stepper motor with the PLC and Microstep Driver.

– Interaction of a PLC with the controller of the industrial robot.

Finally, this project has several areas of improvement such as: the positioning of the chassis can be achieved through a servomotor controlled with the PLC instead of a stepper motor, integrating an HMI connection interface to monitor the processes in real time, generating the connection protocol between the PLC and an industrial network.

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Article **Journal of Technologies in Industrial Processes**
June, 2022 Vol.6 No.14 22-27

Design and construction of pressure leak testers through the analysis of the filling level for the detection of defects in the nozzle of plastic containers

Diseño y construcción de probadoras de fugas de presión por medio del análisis del nivel de llenado para la detección de defectos en la boquilla de envases plásticos

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Abstrac

Plastic Container Manufacturing Process, many equipment has been developed for the detection of defects, for example: vision cameras, pressure test leak testers, colorimeters, hermeticity cameras, etc. each form is designed to detect a specific defect, it is updated as technology improves. Currently, the industry has opted for the use of microcontrollers that help automate industrial processes, one of the most used micros is Arduino due to its simplicity of programming and low cost of operation. The objective of this work is to apply an Arduino system for the monitoring of pressure leak testers in plastic containers. Finally, the paper shows the possible change of a particular system based on PLC with ladder logic language, by a simple system based on microcontrollers.

Upgrading of pressure leak testers, Plastic containers, Microcontroller programming

Resumen

En la industria manufacturera de envases plásticos se han desarrollado diversos equipos para la detección de defectos en los envases, por ejemplo: cámaras de visión, probadoras de fugas de presión, colorímetros, cámaras de hermeticidad etc., cada forma está diseñada para detectar un defecto en específico, el cual se va actualizando a medida que va mejorando la tecnología. Actualmente en la industria se ha optado por el uso de microcontroladores que ayudan a automatizar los procesos industriales, uno de los micros más utilizados es Arduino debido a su sencillez de programación y bajo costo de operación y mantenimiento. El objetivo de este trabajo es aplicar un sistema basado en Arduino para el monitoreo de probadoras de fugas de presión en envases plásticos. Finalmente, se muestra en el artículo que es posible sustituir el sistema basado en PLC con leguaje escalera, por un simple sistema basado en microcontroladores.

Actualización de probadoras de fugas de presión, Envases plásticos, Programación de microcontroladores

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Introduction

Plastic containers produced by the extrusion blow molding process usually present several defects among them: contaminated material, leaks, flanges, fins, etc. Two of the defects that critically affect the quality and functionality of the container are leaks and flanges, since a flange is the dragging of plastic that partially covers the nozzle of the container.

Most of the companies involved in the production of plastic containers have leak testers, which are equipment that detect and reject leaking containers. The newest equipment on the market has been upgraded to detect leaks and angina in a single test. However, for some companies, upgrading this equipment with the supplier often represents a large investment of time and money.

The objective of this work is to upgrade these devices using a microcontroller (Arduino) and expose the design and working principle for angina detection. With the purpose of decreasing the costs for the update of these equipments.

Figure 1 shows examples of the angina defect, the problem that represents this defect can be, from product spills in the filling lines, damage to filling equipment by clogging in the nozzles, etc.. As a consequence of the above, it is called line stoppages, either for cleaning or repair of the equipment.

Figure 1 Plastic container with angina defect
Own Elaboration

Description of the method

A major challenge for engineers is to upgrade old equipment and machines to match the level of functionality of a modern machine.

To modernize the leak tester equipment, it is necessary to renew the test head, because it houses an inductive sensor that sends the signal to the microcontroller when it detects the presence of angina by means of the mechanical activation of the poka-yoke. The head is made up of 5 pieces as shown in figure 2.

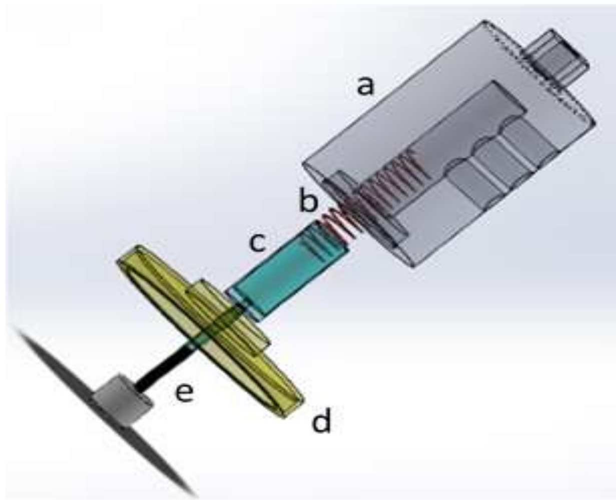

Figure 2 Components of a head [1]

Table 1 describes the functions of each of the head elements.

Nom.	Name	Function
a	Printhead	It contains three holes 2 for the air inlet and outlet and 1 where the inductive sensor will be placed.
b	Spring	Allows the poka-yoke to return to its position once activated.
c	Stem	The poka-yoke of the appropriate diameter with respect to the diameter of the container for angina detection is placed in it, in addition, the spring is placed inside the stem, the case of the stem is the one that slides upwards.
d	Dish	The silicone gasket is placed on it to seal the head with the container nozzle
e	**Calibrator**	Interchangeable aluminum disc according to the internal diameter of the container nozzle.

Table 1 Elements and characteristics of the head [2]

Figure 3 in A shows the position of the stem when the head is lowered to perform the leak test, if the container has angina it will retract the internal spring making the stem rise up to the position of the sensor as seen in B thus sending the signal to the microcontroller.

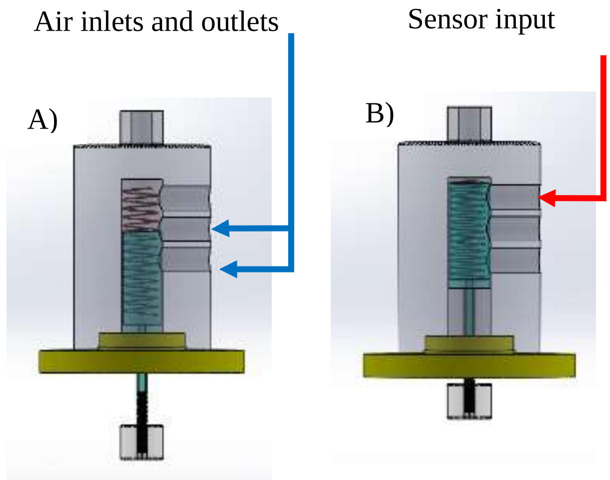

Figure 3 Head position in operation [3]

The signal sent will be processed by the microcontroller, which based on the programming code will open a relay interrupting the leak test, returning the head to its initial position causing the air to escape before the end of the leak test and consequently discarding the container for angina defect.

Circuit design

The elements in Table 2 were used to design the electrical circuit.

Component	Function
Transformer	Reduces voltage from 110V to 12V
Rectifier	Rectifies and regulates the alternating voltage of 12V
Arduino microcontroller	Receives the sensor signal to initiate the programming cycle, which will open the relay for a programmed time after the duration of the received signal.
Inductive sensor	Sends a pulse signal to the microcontroller when the poka-yoke is activated.
Relay	Interrupt tester actuator solenoid valve circuit, to raise pneumatic head actuator and interrupt leakage test

Table 2 Components of the electrical circuit [4]

Figure 4 shows the physical diagram of the proposed electrical system.

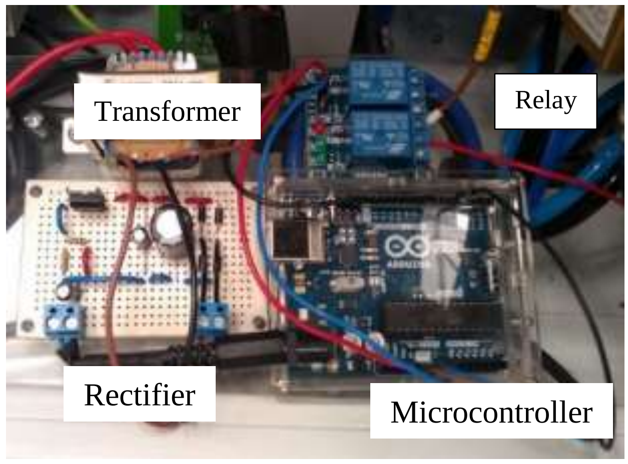

Figure 4 Circuit assembly and components [5]

Connection of the components

The Arduino microcontroller processes the signal received from the inductive sensor to start the programming cycle. The programming code consists of two beats:

First time: the time that the sensor signal must last to start with the relay opening is declared, This time is declared in ms. It helps to ensure that there are no false rejections due to rose problems with the container nozzle when the poka-yoke goes down to start the leak test.

Second time: is the relay opening time, this time is programmed based on the duration of the test time, the opening time must be less than the test time to allow the tester to function correctly.

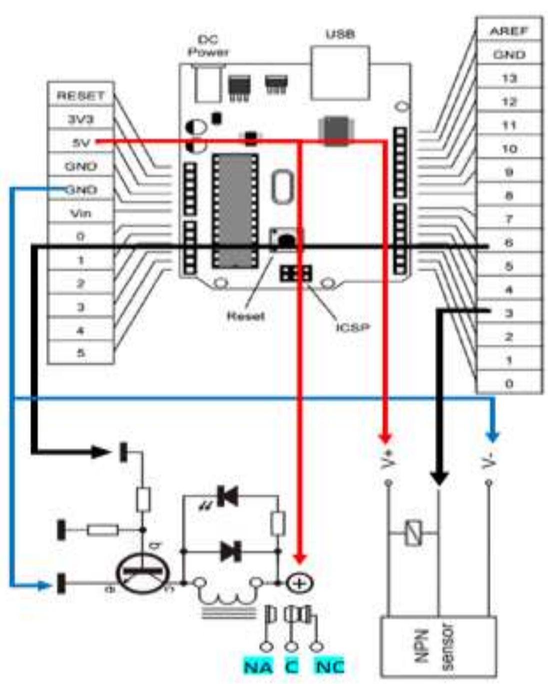

Figure 5 Structure of the proposed circuit
Own Elaboration

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Circuit implementation

To perform the installation, it is necessary to locate the solenoid valve, which activates the pneumatic piston which performs the raising and lowering of the head. The pneumatic and electrical diagram in the tester manual is used to identify the valve, or it can simply be physically traced in the equipment. Figure 7 shows how to interrupt the power supply circuit of the solenoid valve, the relay must be placed in common and normally closed.

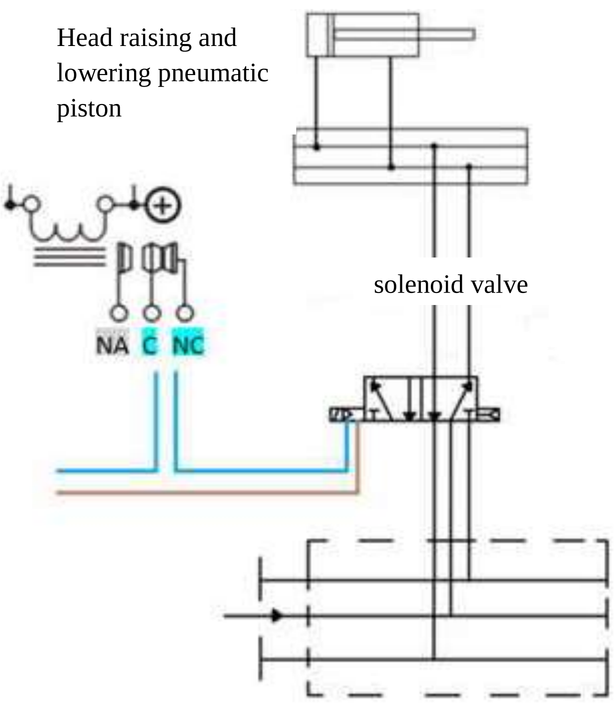

Figure 6 Connection diagram
Own Elaboration

The constructed circuit has a size of 24 x 16 cm. This allows it to be placed inside the panels of the leak testers, some models to mention are testers of the brand W. Asmler and Delta, as shown in Figure 7.

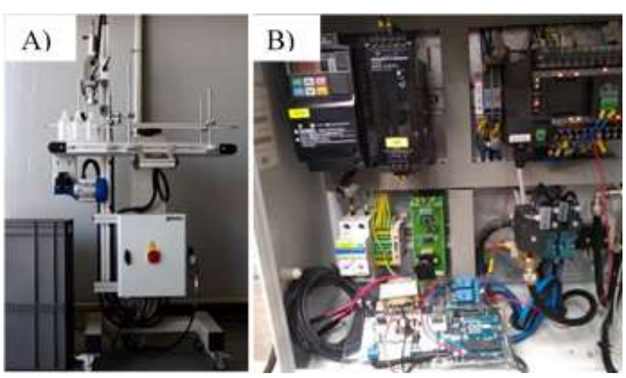

Figure 7 A: UDK050 Delta tester. B: Circuit assembly inside the leak tester panel, DELTA [6].

Results

As already mentioned, leak testers start their test or measurement cycle, starting from the signal of the reflective sensor that detects the presence of the container [7-8]. The test cycle consists of a filling time (T1), during which the tester injects air until reaching a programmed test pressure (P1).

Once this test pressure is reached, there is a stabilization time (T2) in which the air inside the container is stabilized so that the pressure sensor obtains a reference reading which can be equal to the test pressure.

After that comes a test time (T3), during this time the tester will measure the pressure reading inside the container, when the container does not leak the reading measured initially will be maintained with little variation and if the container leaks, the pressure reading will decrease considerably and will be less than the programmed test pressure, based on a previously programmed pressure limit (P2) the tester will reject the leaking container.

If the container has an angina defect, the head will be retracted and will send a signal to the inductive sir, the signal duration time is previously programmed (TS).

When the signal duration time is reached, it immediately triggers the opening of the relay, based on a programmed opening time (TR).

When the relay signal opens, it returns the piston to its initial position causing all the air inside to escape and the container to be rachando by angina, however, it closes again before the end of the programmed test time in order to start the next cycle, since, if it remains open after the test time ends, it will reject all the containers before lowering the piston.

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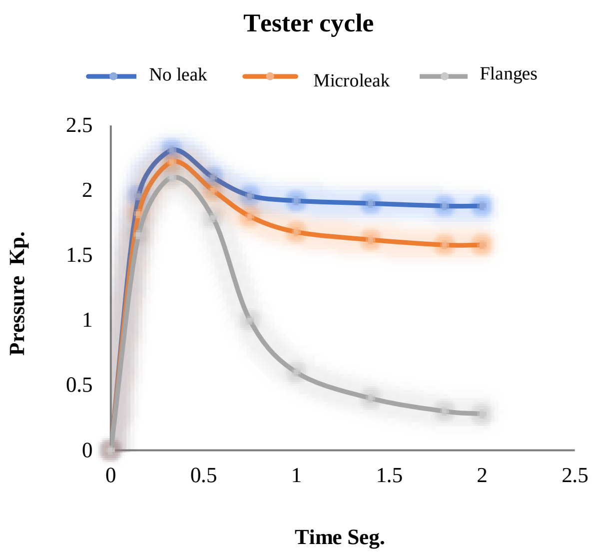

Graph 1 Behavior of the pressure system in the tester and poka-yoke
Own Elaboration

T1: Filling time
T2: Pressure stabilization time
T3: Measurement time
TS: Time of sensor signal duration for relay activation
TR: Relay opening duration time
P1: Test pressure
P2: Pressure limit or minimum allowable pressure after stabilization

Figure 1 shows three examples of pressure behavior based on the following three possible cases:

1. It is the pressure behavior of a container without leakage.

2. It is the pressure behavior of a container with micro leakage. If the leak is larger, the pressure drop will be more noticeable.

3. It is the depression behavior of a container with angina due to the fact that in that time the test is suspended and the air escapes during the measurement time.

Conclusions

The implementation of this update was carried out in different leak tester equipment, also in different products, so it was possible to conclude with the following:

– It was observed that for the correct operation of the Poka-yoke it is necessary to control the factors that influence with the centering of the head with respect to the container nozzle, these factors are; proper centering of the lateral guides, conveyor belt speed and head down speed.

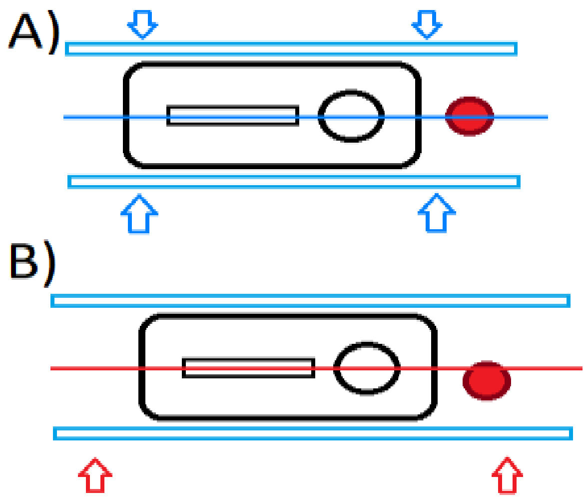

Figure 8 Centering of head guides
Own Elaboration

– A higher efficiency of angina detection was shown in machines with a high production cycle of only 5 pcs per minute, which allowed a test time of 12 sec. for each package.

This allowed to reduce the speed of the conveyor belt, to avoid that, when braking, the container would move by inertia causing it to move off-center with the head, and also to reduce the downward speed of the head piston, thus providing a smooth entry of the head with respect to the nozzle of the container.

The machines with this cycle were those that produced carafes, the carafes had a diameter greater than 45 mm, which allowed a considerable improvement in the centering of the head and completely mitigating false rejections due to a bad centering.

On the other hand, an unconventional operation was observed in machines with a production of 26.6 cans per minute. Mostly on machines that produced one liter containers. Allowing a test time of only 2.3 sec. per container.

Adding the problem that the diameter of the one-liter container was smaller (28 to 38 mm), the production speed and the smaller diameter of the container made it difficult to center the poka-yoke with respect to the nozzle, generating false rejects.

Recommendations

For the upgrade of testers that are on machines with very fast cycles, it will be necessary to implement a mechanical stopper, thus eliminating the movement of the container by inertia when braking the belt between each test, as shown in Figure 9.

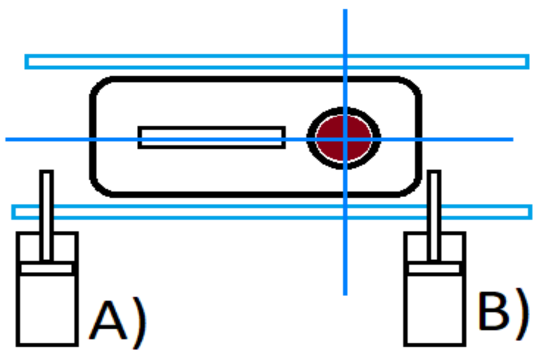

Figure 9 Improved mechanical stop. A) retains the rear container. B) Brakes the container to start test
Own Elaboration

It is also necessary to change the design of the calibrator, giving it a longer chamfer to help center the container as the head moves down towards the container nozzle, as shown in Figure 10.

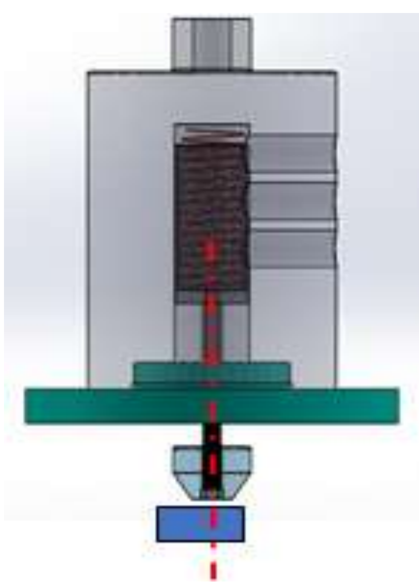

Figure 10 Poka-yoke with a larger chamfer to improve container centering
Own Elaboration

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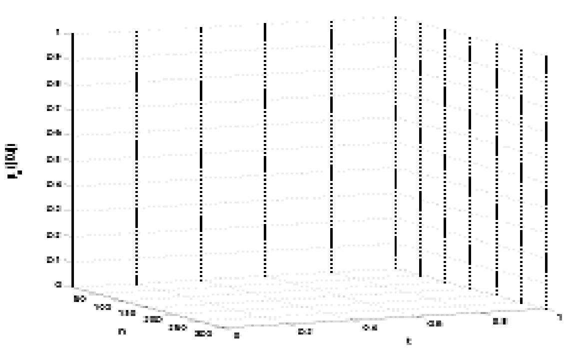

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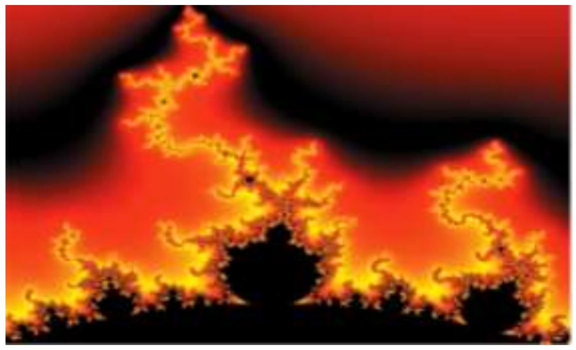

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