ISSN 2523-0344

Volume 7, Issue 18 — January — June — 2023

Journal Industrial Engineering

ECORFAN®

Journal Industrial Engineering, Volume 7, Issue 18, June, 2023, is a biannual magazine published by ECORFAN-República del Perú. AV. La Raza, No 1047 - Santa Ana, Cusco-Peru, CP: 11500. WEB: http://www.ecorfan.org/republicofperu/rj_ingenieria_industrial.php, revista@ecorfan.org. Editor in Chief: SERRUDO-GONZALES, Javier. BsC. ISSN: 2523-0344. Responsible for the last update of this issue Unidad Informática ECORFAN. ESCAMILLA-BOUCHÁN, Imelda. PhD. LUNA-SOTO, Vladimir. PhD. Updated June 30, 2023.

Journal Industrial Engineering

Definition of Research Journal

Scientific Objectives

Support the international scientific community in its written production Science, Technology and Innovation in the Field of Engineering and Technology, in Subdisciplines Production systems design, product quality management, operations research, computer simulation, supply chains, quality certification, hydrometeorology.

ECORFAN-Mexico, S.C. is a Scientific and Technological Company in contribution to the Human Resource training focused on the continuity in the critical analysis of International Research and is attached to CONAHCYT-RENIECYT number 1702902, its commitment is to disseminate research and contributions of the International Scientific Community, academic institutions, agencies and entities of the public and private sectors and contribute to the linking of researchers who carry out scientific activities, technological developments and training of specialized human resources with governments, companies and social organizations.

Encourage the interlocution of the International Scientific Community with other Study Centers in Mexico and abroad and promote a wide incorporation of academics, specialists and researchers to the publication in Science Structures of Autonomous Universities - State Public Universities - Federal IES - Polytechnic Universities - Technological Universities - Federal Technological Institutes - Normal Schools - Decentralized Technological Institutes - Intercultural Universities - S & T Councils - CONAHCYT Research Centers.

Scope, Coverage and Audience

Journal Industrial Engineering is a Journal edited by ECORFAN-Mexico, S.C. in its Holding with repository in Republic of Peru, is a scientific publication arbitrated and indexed with semester periods. It supports a wide range of contents that are evaluated by academic peers by the Double-Blind method, around subjects related to the theory and practice of Production systems design, product quality management, operations research, computer simulation, supply chains, quality certification, hydrometeorology with diverse approaches and perspectives , That contribute to the diffusion of the development of Science Technology and Innovation that allow the arguments related to the decision making and influence in the formulation of international policies in the Field of Engineering and Technology. The editorial horizon of ECORFAN-Mexico® extends beyond the academy and integrates other segments of research and analysis outside the scope, as long as they meet the requirements of rigorous argumentative and scientific, as well as addressing issues of general and current interest of the International Scientific Society.

Editorial Board

Arbitration Committee

Assignment of Rights

The sending of an Article to Journal Industrial Engineering emanates the commitment of the author not to submit it simultaneously to the consideration of other series publications for it must complement the Originality Format for its Article.

The authors sign the Authorization Format for their Article to be disseminated by means that ECORFAN-Mexico, S.C. In its Holding Republic of Peru considers pertinent for disclosure and diffusion of its Article its Rights of Work.

Declaration of Authorship

Indicate the Name of Author and Coauthors at most in the participation of the Article and indicate in extensive the Institutional Affiliation indicating the Department.

Identify the Name of Author and Coauthors at most with the CVU Scholarship Number-PNPC or SNI-CONAHCYT- Indicating the Researcher Level and their Google Scholar Profile to verify their Citation Level and H index.

Identify the Name of Author and Coauthors at most in the Science and Technology Profiles widely accepted by the International Scientific Community ORC ID - Researcher ID Thomson - arXiv Author ID - PubMed Author ID - Open ID respectively.

Indicate the contact for correspondence to the Author (Mail and Telephone) and indicate the Researcher who contributes as the first Author of the Article.

Plagiarism Detection

All Articles will be tested by plagiarism software PLAGSCAN if a plagiarism level is detected Positive will not be sent to arbitration and will be rescinded of the reception of the Article notifying the Authors responsible, claiming that academic plagiarism is criminalized in the Penal Code.

Arbitration Process

All Articles will be evaluated by academic peers by the Double Blind method, the Arbitration Approval is a requirement for the Editorial Board to make a final decision that will be final in all cases. MARVID® is a derivative brand of ECORFAN® specialized in providing the expert evaluators all of them with Doctorate degree and distinction of International Researchers in the respective Councils of Science and Technology the counterpart of CONAHCYT for the chapters of America-Europe-Asia- Africa and Oceania. The identification of the authorship should only appear on a first removable page, in order to ensure that the Arbitration process is anonymous and covers the following stages: Identification of the Research Journal with its author occupation rate - Identification of Authors and Coauthors - Detection of plagiarism PLAGSCAN - Review of Formats of Authorization and Originality-Allocation to the Editorial Board- Allocation of the pair of Expert Arbitrators-Notification of Arbitration -Declaration of observations to the Author-Verification of Article Modified for Editing-Publication.

Instructions for Scientific, Technological and Innovation Publication

Knowledge Area

The works must be unpublished and refer to topics of Production systems design, product quality management, operations research, computer simulation, supply chains, quality certification, hydrometeorology and other topics related to Engineering and Technology.

Presentation

As the first article, we present, *Systematic review: strategic design in the stakeholders* by HIGUERA-ZIMBRÓN, Alejandro & RIVERA-GUTIÉRREZ, Erika, with adscription in the Nova Southeastern University and Universidad Autónoma del Estado de México, as second article we present, *Occupational risks in a manufacturing company, a case study in Mexico* by CASTILLO-VILLALBA, Rocio Anayeli, with adscription in the Instituto Politécnico Nacional, as third article we present, *Method to detect faults in the rotor squirrel cage with low load in permanent state using DWT* by MARTÍNEZ-GARCÍA, Irving I. & PEÑA-CABRERA, J.Mario, with adscription in the Universidad Nacional Autónoma de México, as fourth article we present, *Preliminary Development of an upgrade of a chamber to measure the response of quartz crystal resonators* by LOPEZ-RAMIREZ, Carlos Alberto, MUÑOZ-MATA, José Lorenzo, ROJAS-GARNICA Juan Carlos and CERVANTES-DE LA ROSA, Juan Pedro, with adscription in the Universidad Tecnológica de Puebla.

Content

Article **Journal Industrial Engineering**
June 2023, Vol.7 No.18 1-13

Systematic review: strategic design in the stakeholders

Revisión sistemática de diseño estratégico en los sectores productivos

HIGUERA-ZIMBRÓN, Alejandro†* & RIVERA-GUTIÉRREZ, Erika

Nova Southeastern University, Fischler College of Education and Criminal Justice.
Universidad Autónoma del Estado de México, Centro de Investigación en Arquitectura y Diseño.

ID 1st Author: *Alejandro, Higuera-Zimbrón* / **ORC ID:** 0000-0002-7851-7531, **Researcher ID Thomson:** AAJ-7550-2020, **arXiv Author ID:** https://arxiv.org/a/0000-0002-7851-7531, **SNI CONACYT ID:** 226412

ID 1st Co-author: *Erika, Rivera-Gutiérrez* / **ORC ID:** 0000-0001-6966-2721, **Researcher ID Thomson.** AAJ-7948-2020, **arXiv Author ID:** https://arxiv.org/a/0000-0001-6966-2721, **SNI CONACYT ID:** 247442

DOI: 10.35429/JIE.2023.18.7.1.13 Received January 10, 2023; Accepted June 30, 2023

Abstract

This study is aimed on the strategic design definition, applied from the stakeholders: private sector, government, society, and academia. The pupose is a conceptual approach, analyse features, and processes guided in each sector. The goal is achieved throught the next activities, statement of the problem supported by primary sources, a scientific literature review guides the researcher, organizing, arguing, and composing the review from data bases. A qualitative methodology is based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). The results evidence a conceptual confusion between strategic design and strategic planning. In the conclusions and recommendations expose a gap, nevertheless new research will be designed.

Systematic review, strategic design, stakeholders

Resumen

Este artículo tiene como propósito hacer una búsqueda del término de diseño estratégico sobre la connotación que se usa en los diferentes sectores productivos: industria, gobierno, sociedad y academia; con la finalidad de identificar una aproximación conceptual, analizar las características y considerar sus procesos desde cada una de las esferas. Para lograrlo, primero se establecieron los antecedentes y orígenes del término. Segundo, se hizo una revisión de literatura de los estudios recientes sobre el estado actual que guarda el término, apoyándose de diferentes bases de datos y repositorios digitales. Tercero, el estudio se planteó desde un enfoque cualitativo, basado en un método de revisión sistemática que se apoya del *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).* Cuarto, los resultados se muestran y se discuten a partir de un análisis de contenido. Finalmente, se exponen las conclusiones y recomendaciones del estudio.

Revisión sistemática, diseño estratégico, sectores productivos

Citation: HIGUERA-ZIMBRÓN, Alejandro & RIVERA-GUTIÉRREZ, Erika. Systematic review: strategic design in the stakeholders. Journal Industrial Engineering. 2023. 7-18:1-13.

* Author Correspondence (E-mail: ahigueraz@uaemex.mx).
† Researcher contributing as first author.

Introduction

Strategic design (SD) is an ongoing concept with theoretical, practical and scientific implications. Theoretically, it is a disciplinary engine that works with creativity, innovation, reflection and transformation. These traits are part of thinking capable of generating responses to challenges that influence the human being's own ambition to transcend. From a practical perspective, ED responds to various needs, but one as a consequence of the growth of mankind, and the other because of man's natural ambition. Consequently, the scientific implications are a manifestation that responds, or so it is intended, to the unresolved problems, but with a more rigorous and above all scientific approach.

It is in this context that this initiative to elaborate a Systematic Review of Strategic Design in the Productive Sectors arises. With the purpose of identifying and analysing scientific evidence in relation to the definitions of SD from the connotation used in the productive sectors: industry, government, society and academia; in order to make an approximation of the term, analyse the characteristics and consider the operation processes in each productive sphere. To achieve this purpose, this review first addressed a theoretical framework of reference, in order to understand recent studies or gaps in the literature, as well as to establish questions that respond to the study. Subsequently, the methodological design was based on the Cochran Systematic Review Method (Cochrane Handbook for Systematic Reviews) which allowed us to locate the information from different databases, and thus present the results of the research that will make it possible to establish the following discussion section contrasting references versus results, and finally generate conclusions and recommendations.

Frame of reference

Systematic reviews

Systematic literature reviews (SLR) are a process of identifying the essences of the literature of interest, especially based on primary studies, without devaluing secondary studies. This is achieved by searching for and extracting the most relevant, based on certain parameters (Nerwell *et al*., 2006). An example is the scientific criteria set out by the Cochrane methodology.

The Cochrane Collaboration is an international organisation that brings together the SLRs. In practice it is a non-profit entity created in 1993 with the aim of increasing the quality of health care decisions by preparing, maintaining and promoting the accessibility of SLRs on the effects of health interventions. Its inspiration stems from the earlier ideas of Archie Cochrane, a Scottish medical epidemiologist, who argued that one of the most significant advances in medicine would be the notion that health care services should be based on scientific evidence rather than clinical impression, anecdotal experience, expert opinion or tradition (Urra *et al*., 2010).

It is for this reason that the fundamental instrument for conducting systematic reviews is the Cochrane Handbook. The background of this document shows that they are leaders in conducting SLRs for health care research. The work then followed, based on an international organisation, which integrates research and development centres to review and analyse randomised clinical trials from a global perspective. However, during the 1990s, approaches were established incorporating qualitative data into systematic reviews of research that became an important tool in health care, social sciences and education (Cochrane Handbook, 2012, p. 581).

Historically, this manual, arises with the intention of being used from the application in the health sciences, but currently it is applied from the perspective of other disciplines such as social sciences, humanities, among others. Currently, Cochrane produces reports to influence professional practice. These analyses have a quantitative and in some cases qualitative basis, as will be the case in this research.

Authors such as Gisbert and Bonfill (2004) state that systematic reviews are scientific investigations that present a methodology for synthesising the results of original studies. The characteristics of SLRs are: a) analysis and synthesis of information with a practical approach, b) based on scientific evidence, c) formulate defined questions, and d) use systematic, explicit methods to identify and select studies, critically evaluate, extract the data of interest and analyse.

ISSN: 2523-2517

In the words of Robleda (2019) an SLR can integrate empirical evidence to meet established requirements that respond to research questions. In application, it requires systematising the information, setting out methods for presenting results, and thereby reaching conclusions. The same author argues that in qualitative studies, SL uses methods of observation, diagnosis or prognosis (Robleda, 2019). From this perspective, SL is a viable and efficient mechanism to elucidate relevant information about a phenomenon of interest.

An SLR makes it possible to report findings or results of studies that are presented by different authors, confirming or contrasting information with each other. In confirmation, there are no definitive answers because the reviews are modified over time; however, it is a starting point to begin the search for studies that respond to established needs supported by systematisation of information; methodical and procedural. Even in contrasting results, for example, accurate, biased or false data can be identified as a consequence of the currency of their application or scientific publication.

Nowadays with open access (OA) there is such a large amount of data that it is complex to synthesise, due to the large number of volumes per discipline. For this reason, an alternative is the use of the RSL, as it allows the location, classification and orderly and structured management.

According to Beltrán (2005) in an SLR study, there are two types of reviews, one systematic and the other non-systematic or narrative. In his document, he argues that the traditional method is the narrative method, but with weaknesses that do not allow a rigorous criterion to be maintained in the collection of data. For this reason, the systematic review must follow a rigorous and critical method to achieve greater precision in the estimation of data that will help generate information for decision-making. Therefore, the SLR study must include the following characteristics, which stand out for their rigorousness: a) an approach based on the formulation of a research question; b) a search strategy clarifying the study phenomenon, c) consideration of structured selection criteria, d) rigorous and critical analysis of information, and e) synthetic with a qualitative or quantitative orientation (meta-analysis) (Beltran, 2005) (Beltran, 2005).

In short, SL is a scientific strategy for obtaining evidence from different studies, primary or secondary, which are located in information units such as repositories or digital libraries, among others. Which, due to their characteristics, formulate questions of interest through the search, collection, selection, analysis, and communication of different research: basic or applied, which make it possible to answer unknowns.

Strategic design

The evolution of strategic design (SD) denotes a presence in the development of products and services. In the 1980s it was implemented under an operational (individual) perspective. Focused on generating results in the creation of new products for distribution in retail shops. The model focused on presenting purpose, actions, business, products and services. In the 1990s, as the issue of competitiveness was a niche production, the tactic was a guide to business success. It was expressed through technology and innovation as manifestations of progress. Later at the turn of the century, its manifestation was at the strategic level with a major influence of Harvard and Stanford business schools in inducing the practices of strategic design management.

DE or design management (DM) in the words of Rubio *et al*. (2016), propose dynamic ways of looking at design. According to the authors, DM is a discipline that generates solutions to visual, utilitarian, objectual or spatial communication problems through the development and innovation of projects (Rubio *et al*., 2016). However, it is subscribed that there are particular connotations that must be defined from each perspective of design and strategy, as both terms represent a symbiotic relationship, structuring solutions under a wide range of perspectives. The background of design goes back to the origins of mankind. From the satisfaction of needs for subsistence in an environment. Now, without going into detail in an epistemological definition of the term, it is logically understood that just as the universe, the world and humanity have evolved, so has design: the central idea is that the whole is design. It is a complex phenomenon of free thinking that generates chaos in the senses to construct representations of universally subjective, but also perfect, imaginary infinity.

ISSN: 2523-2517

Holland and Lam (2014), in their book Managing Strategic Design, argue that design is an insurmountable problem, but to manage it one must try to operate with ideas, and they propose a strategy: first, to review the meaning of the phenomenon associated with design; and second, to try to refine or induce a new vision. From this perspective, it can be interpreted that design shows a dichotomy: it is a problem and it is also a solution. In a reflection, it is that which resembles a designer's gaze. Usually design poses a process: an idea or phenomenon thought in a sequence with a determined end. Systematically, it frames a series of steps (process) to achieve the development of a product or service, regularly called designs. Therefore, design is also virtuous, as it manifests a process and a result.

In other words, design in practice requires creativity and innovation. Both elements play an important role in management. In organisational practice there is a decisive influence from the so-called marketing, not only in the social but also in the business sphere. However, it is argued that the fuel it requires to function or produce movement is strategy. Mintzberg (2020), in his book Strategy Safary, considers that there are various definitions, it is a tactic, it is a specific manoeuvre to outwit an opponent or competitor. In the exercise there are various interpretations of the concept where the so-called 5P'S are offered: plan, ploy, pattern, position and perspective (plan, ploy, pattern, position and perspective).

Holland and Lam (2014) interpreted strategy in terms of a process as starting with a plan that sets out a path of actions that indicate what to do and how to do it. Second, tactics are perhaps invisible, a ruse or trick that could often be interpreted as dishonest. However, tactics are the backbone that helps to gain an advantage over competitors through creative thinking in the search for new opportunities. Third, models are proven processes or methods. That is, the way things are done. The practical exercise identifies that there are things that are better developed in one place than in others; there are products that are better made in one place than in others; or there are services that are better offered in one place than in others. That which is done better is the essence of success.

Fourth, position refers to the should be, the goal or objective of the strategy. Fifth and finally, the perspective is the outlook or vision to be achieved (Holland & Lam, 2014).

In any case, for design to be strategic it must structure processes with useful, efficient and effective outcomes. This is regardless of the causes of the sectors to which it refers: industry, government, society and academia. It is a fact that the sum of the concept of strategic design is a challenge from various perspectives. But before continuing with the analysis, it is essential to be aware of other viewpoints.

Papanek (1971) proposed several decades ago that the issue of linking design with strategy was a tool for solving social, environmental and economic phenomena. In its essence, he identifies that for decades there have been challenges that have been solved, others have not, and DE is an adequate and current mechanism to face adversities. Busayawan (2017), conceives that strategy in design is an added value. It can be interpreted that design plus strategy generates a utilitarian versatility that becomes an operational scaffolding for the productive and social sectors. It is a solution in the world.

A general review of the concept, by various sources such as the Design Council in United Kingdom (UK), Design Management Institute (DMI), the Royal College of Art and Business School of Imperial College London, the Institute of Design at Stanford University, Business Design Studio at Rotman School of Management, and schools of Design, affirm that strategic design is a tool that is widely recognised as a trigger for innovation and development, which is supported by the disciplines for the achievement of projects that converge with the subjects (Busayawan, 2017).

Strategic design is also complemented by design thinking (DT). It especially refers to all those who are not trained as designers. DT requires the full use of the brain, reflection, concentration, and stimulation of ideas to visualise the future. Futurists using DT generate visions, facts and analyse contexts, as well as possessing the ability to select, evaluate critical signals of the future. Thus, DT is a symbiotic catalyst for the incorporation of other disciplines in the evolution of strategic design.

ISSN: 2523-2517

Therefore, in this era Strategic Design and Design Thinking are contributing axes for different dimensions: economic, ecological and social. All articulated to generate progress and national development. It is proven that the potential of such strategies enables global connectivity. From the origins of free trade or globalisation, DE marks gradual consonants with potential effects, for example: it emerges from operational levels (planning, design and quality); it evolves to tactical levels (strategic, develops products, and poses processes, is communicative, creates manufacturing, detonates research, is semantic and user-centred), currently it is strategic (innovation, branding, business model, experiences, social, sustainable and consultancy) (Holland & Lam, 2014).

Research questions

The above has provided evidence of the term's currency and applicability. Therefore, ED raises concerns that can henceforth contribute to research and its development. The ED has permeated different productive sectors. But, in practical terms, it is important to identify or recognise concepts, features or characteristics, processes for the various dimensions or from the productive sectors. Consequently, the following questions arise to help guide this systematic review study on ED.

1. How the productive sectors (industry, academia, government and society) define the ED.

2. What characterises the ED in each of the productive sectors (industry, academia, government and society)?

3. What are the processes followed in each of the productive sectors (industry, academia, government and society) regarding the ED?

Methodological design

This section describes the methodology used to define the scope of the information found, its analysis, and to determine its usefulness, based on the elements necessary to carry out a SR. In this sense, the procedure allows the answers to the research questions posed to be obtained.

Therefore, this study proposed the identification and analysis of studies on the concept of strategic design with respect to the connotation that is used in the different productive sectors: industry, government, society and academia.

The RS methodological approach, based on the Cochrane Handbook (2011) makes it possible to find recent information in relation to the established criteria. The study design corresponded to an analysis of studies on the strategic design concept, based on the guidelines established in the Cochrane Handbook of Systematic Reviews of Interventions (2011) by the Iberoamerican Cochrane Centre, according to the following stages: a) Definition of the topic by clearly defining questions, establishing inclusion criteria; b) Search for studies, possible sources of information; c) Selection of studies and collection; d) Assessment of risk of bias and quality of information; e) Analysis of data collected; f) Presentation of results; and g) Interpretation of results. Based on the above, an identification and analysis was carried out to reflect a scenario. As close as possible to the reality in which the phenomenon under study occurred. This made it possible to establish a degree of validity and reliability in the research consulted.

Consequently, the first step was to identify the theme or topic of the research using the systematic review methodology. Second and third, a selective search for information was carried out. Fourth, the criteria were established. In phase five, data analysis was carried out by experts (filtering). The sixth and seventh phases were developed after the search for references, research, articles or other specific studies.

Research protocol

The intention of establishing a protocol for this study allowed us to optimise the search for research, studies, articles and all types of documentary material in order to identify, select, analyse and synthesise the findings of the most relevant studies and link them to the questions posed (Moher *et al*., 2009). Likewise, a search was carried out for primary studies on the connotation of strategic design used in the different productive sectors: industry, government, society and academia.

ISSN: 2523-2517

Based on the above, the variables of the study focused on: strategic design and productive sectors. In order to identify a conceptual approach, analyse the characteristics and consider their processes from each of the fields. The study considered: rigorously selected studies in its selection process, application of inclusion and exclusion criteria, studies focused on scientific evidence, relevant data extraction, as well as obtaining satisfactory responses to the study approach according to the systematic review methodology (Cochrane Handbook, 2011; Nooan, 2010) used in this protocol, which enabled a specific search for relevant studies and existing information.

Search process

It is important to note that a process of planning, structuring and preparation was essential for the search for information. Therefore, the Preferred Reporting Items for Systematic Review and Meta-Analyses: PRISMA (Moher *et al*., 2009) guide was applied. This guide defined the criteria for conducting the entire systematic review process.

Sources of information

Based on the concepts of strategic design, productive sectors (industry, government, society and academia), the respective search was determined; this was the basis for establishing the eligibility criteria (described below) in the data hubs used until the data that met the defined criteria were found.

Databases

International and national research, digital libraries and institutional repositories were consulted, with indexed and refereed journals, as well as publications from the last ten years, such as Proquest, Eric, Ebsco, Redalyc, Latindex, Scielo, Web of Science, Dialnet, Google Scholar, Ecorfan, among others, both in Spanish and English versions.

Selection of studies

The selection of studies was fundamental to answer the research questions supported by the Cochrane Handbook of the Iberoamerican Cochrane Centre (2011).

First, a preliminary review was conducted, taking into account the title, abstract, as well as references; subsequently, inclusion and exclusion criteria were considered. Secondly, it was determined whether the documents were research articles and whether they referred to the concept of strategic design as applied to the productive sectors: industry, government, society and academia. This was done on the basis of those documents that were linked to the axes of the research.

Eligibility criteria

The procedure for the search of the studies was a) whether research or studies had been carried out previously concerning the phenomenon, b) the purpose of obtaining as many reliable sources as possible. In this way, the respective analyses will be carried out in order to be able to identify and define the criteria for including or excluding the corresponding articles.

According to Saini and Sclonsky (2008), in the selection of primary sources, in addition to considering the inclusion and exclusion criteria, it was important to take into account the following eligibility criteria for all SR: 1. Documents to be evaluated: Primary studies that were developed during the period 2012 to 2022. 2. Variables: Include at least one of the two variables defined for this study. 3. Studies: Topic Strategic Design definition, use and application in the different productive sectors: industry, government, society and academia; also written in Spanish or English. 4. Search: Databases, institutional repositories, books, journals focused on design, management and education. 5. Types of documents: Preferably indexed and refereed published articles. 6. Criteria: Application of inclusion and exclusion criteria.

Inclusion and exclusion criteria

According to the Cochrane Handbook of Systematic Reviews of Interventions (CCI, 2011), as well as Saini and Schlonsky (2008) highlight the importance of defining inclusion and exclusion criteria in a systematic review, prior to the selection of primary sources of information. Inclusion criteria will determine which documents will be part of the study and exclusion criteria will allow for the early elimination of those that meet the criteria.

Inclusion criteria

These are those studies that were found taking into account the search criteria. All those that are linked or related to the questions posed, particularly those referring to strategic design and its connotation with the productive sectors (industry, government, society and academia). Therefore, documents published during the period 2012 to 2022 were considered.

Exclusion criteria

For these criteria we did not consider documents that presented any type of bias, as well as those published in languages other than Spanish and English. In addition, studies that were too long or extensive in relation to the phenomenon under study were excluded, as it was not possible to obtain concrete conclusions focused on the subject matter.

Instruments

The instruments used were designed by the authors, based on the model defined in the Cochrane Handbook of Systematic Reviews of Interventions (2011): Summary Content Record (SCF); Verification Matrix for Valuation and Source Selection (VVSF); Matrix for Organising and Classifying Information (MOCI); and Filter Expert Checklist (FCEL).

Summary content card (SCF)

In this file (FCR), the research consulted as primary sources was recorded, and a summary was made of its content. The purpose of the FCR was to store the information consulted and analysed as a whole. It also included the title of the research, author(s), date of publication, database, key words, type of publication, as well as a section for comments (personal and/or filtering experts).

Verification matrix for assessment and selection of sources (MVVSF)

Based on this matrix (MVVSF), the previously defined inclusion and exclusion criteria were applied. Thus, the primary research was evaluated and selected on the basis of both its content and the contribution it made to the study. This allowed for a measurement of the quality of the research, as well as the variables.

Matrix for organisation and classification of information (MOCI)

In this matrix (MOCI) the basic information of each study was incorporated. On the one hand, the title of the research, author(s), date of publication, type of publication, database and keywords, research approach, methodology, results obtained, conclusions, contributions. In addition, the criteria included: currency (no more than 10 years) reliability (verification of information in recognised databases); source of information (primary sources); scope of the study (level of specialisation).

Checklist for filter experts (LCEF)

This instrument had the particularity that it was designed under the structure of a checklist. The information presented was assessed, organised and evaluated by filter experts (previously selected), determining whether or not it contributed to the research, providing answers to the questions posed. Some of the items considered were: title of the research, author(s), date of publication, database, key words, type of publication, as well as a section for comments (filter experts).

Procedure

In order to develop this study, a series of phases were followed, based on what is established in a systematic review (Rousseau *et al*., 2008). First, based on the purpose and questions of the research, the relevant material for the study was identified and the number of reliable sources was selected to ensure validity and reliability. Second, we considered the procedure established by the Cochrane Handbook of Systematic Reviews of Interventions (CCI, 2011), which included three phases: 1) locating, 2) selecting, and 3) evaluating the selected studies, as well as the process of data extraction and application (primary sources, databases and institutional repositories). Third, the final selection of studies was made, based on inclusion and exclusion criteria for the initial selection. The analysis of these sources had to answer the research questions and whether or not the risk of bias was present. Fourth, the final articles were identified in order to: a) extract the specific information or data, b) perform the respective analyses and syntheses, and c) interpret the results.

ISSN: 2523-2517

Participants

Due to the nature of this study, no human beings are included in this systematic review, and consequently, there is no direct link with the designers. Therefore, and in accordance with the criteria of a systematic review, the sample consisted of the final 28 studies selected.

Assessment of the validity and quality of the selected studies

Petticrew and Roberts (2006) state that every study must have internal validity that lends credibility. This provides security to the instruments that were applied. At the same time, this internal validity is accompanied by external validity, where the results obtained can be socialised and transferred to other contexts. Therefore, as part of the assurance of validity and reliability, those instruments that showed rigidity in their methodological processes were identified.

Risk of bias

A document review was carried out for this study. It was necessary to limit the search for sources according to the established criteria, limiting the number of documents selected. Consequently, the possibility of a risk of bias arose; however, in the selection of final primary sources it was emphasised that certain criteria of the study had to be present and thus not affect the validity of the study.

Delimitations

Creswell (2013) states that delimitations in a SR reduce the scope of an investigation, which has been evident in this study, considering both the time and the search for significant primary sources that met the inclusion and exclusion criteria. However, this did not affect the development of the study.

Results

The purpose of the study focused on strategic design, with respect to the connotation used in the productive sectors: industry, government, society and academia; in order to be able to identify a conceptual approach, analyse the characteristics and consider its processes from each sphere.

Therefore, the following is a description of the way in which the research papers that met the eligibility criteria were selected, and those that did not comply with the respective stages were excluded. Consequently, the systematic review was carried out. The way in which the search and selection of the research papers was carried out, their characteristics, individual results and a synthesis of the results are also shown. In short, a correlation was made between the research questions and the results of the study.

Search and retrieval of studies

On the basis of the protocol established by the systematic review method, a rigorous search for information was carried out, based on the key words of the study (strategic design, productive sectors, industry, government, society and academia) in various prestigious databases, in accordance with what was established in the selection rules of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses PRISMA 2009; 210 studies were identified using the Summary Content Sheet instrument; Using the Checklists for Assessing and Selecting Sources instrument, where assessment criteria were applied, 150 articles were excluded for not meeting the criteria defined for this study, leaving only 60 articles which, following the SR protocol, were applied the Matrix for the Assessment and Selection of Primary Sources instrument, where once the information had been filtered, 20 articles were eliminated, leaving a total of 40; they were subsequently analysed and reviewed in full text by filtering experts. Afterwards, by means of the Checklist for Evaluation of Individual Filter Experts instrument, as well as the contrast of the articles with the research questions in order to define the contribution of each article to provide an answer, another filter was carried out, in which 12 documents were excluded. Therefore, in the end, 28 studies were those that met the rigorous criteria established by the SR method.

Characteristics of the studies

Type of study. The research that was analysed using the SR method was descriptive, experimental and non-experimental in nature. Table 1 shows that most of the studies were descriptive: 18 studies (64%), 22% experimental and 4 (14%) non-experimental.

ISSN: 2523-2517

Study	*f*	%
Descriptive	18	64
Experimental	6	22
Non-experimental	4	14
Total	28	100

Table 1 Types of studies
Source: Own elaboration

Methodology. Based on the studies validated for the application of SR, they focused on mainly qualitative, then quantitative or mixed methodologies. In which qualitative methodology was the most used by the total of the 28 studies, corresponding to 100%.

Instruments. Regarding the validated studies, the information was collected through the application of mostly questionnaires (18), reaching 64% of the total number of instruments (see Table 2):

Instruments	*f*	%
Questionnaires	18	64
Content analysis	6	22
Case studies	4	14
Total	28	100

Table 2 Types of instruments used in the validated studies
Source: Own elaboration

Sample. The results obtained to carry out the systematic review belong to the analysis of 28 articles that were validated by means of the filter experts. These are the result of the 210 studies that were located in various specialised databases, as well as institutional repositories. It is worth mentioning that the 28 articles were published from 2010 onwards and are linked to the object of study of the research.

Individual results of the studies

Based on the purpose and the questions that guided the research, table 3 shows the summary of the 28 final studies selected for SR, where the first column presents the productive sector; the second column shows the number of studies that addressed the ED; while the third column shows those that applied strategic planning.

Productive sectors	ED	EP
Government	3	2
Industry	7	1
Society	6	1
Academy	4	3
Total	20	8

Table 3 Results of studies based on the productive sector
Source: Own elaboration

In summary, the SR results confirm the application of strategic design in the different productive sectors: industry, government, society and academia; where in some cases the concept is defined and characterised. However, there are no SD processes in each of these spheres, making it clear that there is a need to make it visible in the field of design. However, it was also detected that in some studies, even when the use of strategic design was mentioned, in reality they are referring to the application of strategic planning.

Results related to the research questions

The results from the three research questions posed in sequential order are presented below.

Research question 1: How do the productive sectors (industry, government, society and academia) define the ED?

Based on the 28 final studies derived from the SR, the findings showed that depending on the sector (industry, government, society and academia) is the way ED is conceived, where not always the concept applied refers to strategic design, but to strategic planning (SP). The studies make it evident that the conception of ED in some sectors is therefore unclear:

First, in government, SD is conceived as, the application of methodologies that establish a direct relationship with users, a redefinition of approaches based on scientifically rigorous, creative research, as well as an in-depth intervention of the researcher; where efficient, fair, inclusive and sustainable solutions to social problems are promoted. Thus, the ED is characterised by the creative development of structures with the permanent participation of users. They consider that they generate sustainable and fair solutions for the demands of the sector and therefore of society; it is emphasised that everything is centred on the user, where it is sought that the products are adapted to the needs of the user.

ISSN: 2523-2517

Secondly, in industry, ED refers to the development and implementation of design strategies, through integrated planning focused on the company or organisation through tangible and intangible product innovation. On the one hand, focused on achieving the company's business objectives. On the other hand, in response to economic, environmental and social problems, through the application of design methods and tools, focused on the user experience, generating fair, socially responsible and sustainable economic value.

Thirdly, society, the authors agree that ED focuses on responding to problems of products or services that have the potential to improve the social and cultural conditions of human beings. They also highlight the need to use strategies focused on the user, developing proposals for tangible or intangible products through a design process defined according to the needs of the user(s).

Fourth, academia, for this sphere, research agrees that DE serves as a competitive tool for educational institutions; to develop comprehensive strategies and solutions. Consequently, to propose strategies and solutions of value in the short, medium and long term.

Second research question: What characterises ED in each of the productive sectors (industry, government, society and academia)?

The findings make it evident that, regardless of the productive sector, ED is characterised by the development of tangible and intangible user-centred products.

Third research question: What are the processes that follow from DE, for each of the productive sectors (industry, government, society and academia) to strategic design?

From the studies, it is confirmed that there is a knowledge gap when talking about a specific process to develop or implement SD. On the one hand, 25% of the studies take user-centred design methodologies as a basis. On the other hand, 75% of the studies do not have a defined process; however, they apply or integrate strategic planning into the design process, appropriating the EP process and its components, regardless of the sphere or productive sector (industry, government, society and academia) in which the users' needs are focused.

Discussion

In this section, both theoretical and practical aspects were discussed. In other words, the contrast between what the authors proposed versus the results obtained. In this sense, the discussion starts from the research questions:

Research question 1

The answer to the question of how the productive sectors (industry, academia, government and society) define ED was that there are coincidences in some of the studies analysed in relation to the definitions of ED. The findings identify well-supported definitions in the industry and society sectors, according to Rubio *et al*. (2016), Holland and Lam (2014) and Busayawan (2017). The common denominator, in identifying a conceptual approach, is that ED is a structure with processes that generate outputs for the generation of products that satisfy human socio-cultural, economic and environmental conditions. However, there are other studies, according to the results, that focus on the definition of the ED as being equal to that of strategic planning. Especially those studies with a governmental and academic orientation. Both sectors perceive the ED as a plan that requires a diagnosis, vision, mission and objectives with actions. This result has several theoretical, practical and research implications. In the first, it is identified that the definition of the term is not conceived, rather it is confused. In the second, it is argued that the purpose is more important than the means. And thirdly, that the research lacks scientific rigour.

ISSN: 2523-2517

Research question 2

The question concerned how ED is characterised in each of the productive sectors (industry, academia, government and society). The findings show, as already stated in answer 1, two positions. One position in the industry and society sector focuses on its definition and structure. Both sectors follow a strategic design method to face adversities and establish their projects. This characterisation is related to research, sense, idea, prototyping, implementation and evaluation of results. In each of the stages, some tools to achieve success were proposed. In research, mapping, exploration, impacts, and modelling are required. Sense, people, affinity mapping, and SWOT analysis. Ideation, brainstorming, creativity, matrices, holistic studies and engagement. The prototype, tests, examinations, research and development, and projections, among others. And implementation and evaluation is built with the interaction of evaluations, business models, and impact analysis. The second position, that of the governmental and academic sector, is oriented towards the use of strategic planning. Strategic planning is an administrative process, as already said, it poses strategies to develop a project, plan, pattern, position, perspective and tactics.

However, in this case, the results show that in most of these sectors, a plan is projected that arises from a diagnosis, the mission, vision, objectives, strategies, goals and action plan. Given this finding, the authors of this study consider the data to be chaotic. It is unbelievable that Strategic Design is confused with Strategic Planning, as it is shown that both concepts are different by definition. The characteristics in each differ in their definition and procedures, and the results pursued are likely to be different, or not to result in the intended expectation. Therefore, this study shows that the existing CLN is not sufficient to characterise Strategic Design from the government sector and academia. It is likely that more studies with the appropriate membership are required to obtain data and make better decisions.

Research question 3

It is necessary to understand the processes that follow from ED for each of the productive sectors (industry, academia, government and society). However, Holland and Lam (2014) argue that DE starts from a process, through a series of steps to achieve the development of a product or service, tangible or intangible. The SR findings made evident the lack of application of these design processes in the development of products or services. On the one hand, in the industrial and social sector, it is apparent that a strategic design process is followed. Defined and structured, based on the conceptual axes of the method, its instruments and processes, in addition to the analysis tools. Therefore, there is evidence that the strategic design process, in both cases, enables the desired innovation or development.

The data show that the projects that were carried out were in some way executed with respect to the idealisation or prototype that was proposed. On the other hand, in the governmental and academic sector there is a perceived confusion in the strategic design process. As has already been proven, the process followed is not that of design but that of planning. Strictly speaking, it is not about minimising strategic planning, but on the contrary, the intention of these authors is that the methods are not being used properly and therefore the results may not be achieved because the process is not adequate. In the studies reviewed, it is at least notable that a process aligned to strategic planning was followed, however, in the title of the studies the variable strategic design was identified. However, when reviewing the content of the study, it was identified that there was nothing related to this variable, but rather to the strategic planning variable.

Conclusions

In short, this study focused on researching the topic of strategic design in terms of the connotations used in the different productive sectors, in order to identify a conceptual approach, analyse the characteristics and consider its processes in each of these areas.

ISSN: 2523-2517

Littell *et al.* (2008) emphasise that systematic review is a systematically organised process that enables the development of new insights in relation to existing evidence on a given problem, being exhaustive.

In this case, the conclusions can be focused on the three objectives that were framed, firstly to identify the conceptual approach, secondly to analyse the characteristics and thirdly to consider the processes, all related to strategic design. In relation to the conceptual approach, it is concluded that the term SD finds currency in studies related to industry and society. This is not the case in government and academic studies. In the latter it is embarrassing that academic institutions, cradles of knowledge, their administrations are unable to define and use the concepts adequately. On the analysis of the characteristics of the ED, it can be said that the conceptual theoretical framework for the industry and society sectors are used in a versatile and adequate way. However, the evidence shows that the characteristics of the ED are clearly defined and described, which indicates that there is a good understanding of the use of this methodology in these sectors. Meanwhile, it has been emphasised that there is confusion between the process of strategic design and strategic planning. While in each area there is evidence of appropriate use, there are gaps in its application in government and academia.

Limitations of the study

Creswell (2013) notes that limitations in a systematic review study are visualised in the possible weaknesses identified by the researcher, as well as relating to possible shortcomings in the measurement of variables, limited number of studies, sample size, data collection or data analysis. In this study, the search and selection work required in the systematic review was inherent to the presence of limitations or deviations of various kinds that could have originated in the procedures used for the selection, analysis or synthesis of all the information obtained. This also extended to the contents of the information sources consulted. Another limitation that arose in methodologies (SR) such as the one used in this study was the influence of the individual criteria or thinking of the selected authors, which could affect the ability to generalise some of the information obtained.

Recommendations

It is recommended that further studies on framing the conceptual differences between a strategic design and a strategic plan be generated for each of the government, academia, society and industry sectors.

References

Beltrán, O. A. (2005). Revisiones sistemáticas de la literatura. *Revista colombiana de gastroenterología*, *20*(1), 60-69. URL: https://www.redalyc.org/pdf/3377/337729264009.pdf

Centro Cochrane Iberoamericano, traductores. Manual Cochrane de Revisiones Sistemáticas de Intervenciones, versión 5.1.0 [actualizada en marzo de 2011] [Internet]. Barcelona: Centro Cochrane Iberoamericano; 2012. http://es.cochrane.org/sites/es.cochrane.org/files/uploads/Manual_Cochrane_510_reduit.pdf

Centro Cochrane Iberoamericano (CCI), traductores. Manual Cochrane de Revisiones Sistemáticas de Intervenciones, versión 5.1.0 [actualizada en marzo de 2011] [Internet]. Barcelona: Centro Cochrane Iberoamericano; 2012. URL: http://www.cochrane.es/?q=es/node/269.

Gisbert, J., & Bonfill, X. (2004). ¿Cómo realizar, evaluar y utilizar revisiones sistemáticas y metaanálisis? *GastroenterolHepatol*; *27*(3):129-49. http://www.elsevier.es/en/node/2030405

Holland, R., & Lam, B. (2014). *Managing strategic design*. Bloomsbury Publishing.

Littell, J. H., Corcoran, J., & Pillai, V. (2008). Systematic reviews and meta-analysis. Oxford, UK: Oxford University Press.

Mintzberg, H., & Laasch, O. (2020). Mintzberg on (ir) responsible management. In *Research Handbook of Responsible Management* (pp. 73-83). Edward Elgar Publishing.

ISSN: 2523-2517

Moher, D., Liberati, A., Tetzlaffy, J., & Altman, D. (2009). The PRISMA Group (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement [El Grupo PRISMA (2009). Artículos de traspaso preferidos para las revisiones sistemáticas y meta- análisis: La declaración PRISMA]. http://www.prisma-statement.org/usage.htm

Newell R, Burnard P. (2006) *Vital Notes for Nurses: Research for evidence-based practice*. New Jersey: Wiley Blackwell.

Noonan, E. (2010). Systematic reviews: An introduction [Revisiones sistemáticas: Una introducción]. URL: http://www.campbellcollaboration.org/artman2/uploads/1/1-Oslo_SR_100608_v1.pdf

Papanek, V. (1971). *Design for the Real World: Human Ecology and Social Change*. New York: Pantheon Books, 394 p.

Papanek, V (2019). *Design for the real world*. USA: Thames and Hudson Ldt.

Petticrew, M., & Roberts, H. (2006). How to appraise the studies. En M. Petticrew & H. Roberts (Eds.), Systematic Reviews in the social sciences: A practical guide (pp. 125-163). Malden, MA: Blackwell.

Robleda, G. (2019). Cómo analizar y escribir los resultados de una revisión sistemática. *Enfermería Intensiva*, *30*(4), 192-195. DOI. https://www.researchgate.net/profile/Gemma-Robleda-2/publication/336455586_Como_analizar_y_escribir_los_resultados_de_una_revision_sistematica/links/5e072d9192851c83649fe163/Como-analizar-y-escribir-los-resultados-de-una-revision-sistematica.pdf

Rubio, T. M. A., Higuera, Z. A., Victoria, U. R., Rivera, G. E., Utrilla, C. S.A., & Santamaría, O. A. (2016). *Diseño estratégico sostenible. Fundamentos teóricos y aplicaciones éticas para el comercio justo y las comunidades autopoieticas*. Toluca, Estado de México: UAEMéx.

Saini, M., & Shlonsky, A. (2008). Developing a protocol for systematic synthesis within C2 reviews: Expanding the evidence for decisions in education, social welfare and 163 criminal justice. URL: http://www.campbellcollaboration.org/artman2/uploads/1/Methods_Saini.pdf

Urra, M. E., Barría, P. (2010). La revisión sistemática y su relación con la práctica basada en la evidencia en salud. *Rev. Latino-Am. Enfermagem*. jul ago 2010. Universidad Austral Chile. URL: http://www.scielo.br/pdf/rlae/v18n4/es_23.pdf.

Article **Journal Industrial Engineering**
June 2023, Vol.7 No.18 14-20

Occupational risks in a manufacturing company, a case study in Mexico

Riesgos laborales en una empresa manufacturera, un caso de estudio en México

CASTILLO-VILLALBA, Rocio Anayeli*†

Instituto Politécnico Nacional, Sección de Estudios de Posgrado e Investigación

ID 1st Author: *Rocio Anayeli, Castillo-Villalba* / **ORC ID**: 0000-0001-9954-526X, **Researcher ID Thomson**: ERV-6680-2022, **CVU CONACYT ID**: 1015707

DOI: 10.35429/JIE.2023.18.7.14.20 Received March 15, 2023; Accepted May 30, 2023

Abstract

The objective of this investigation was to recognize the occupational hazards to which operators in the manufacturing production area are exposed in order to subsequently seek to establish a safety program. Carrying out the collection of information through semi-structured interviews, to later collect and find the frequency of the most recurrent words, with the subjective point of view. The result was to find that the operators most recognize the risks in the mechanical category, representing 23.07%, while the ergonomic risk category is the lowest with 3.84% together with the chemical one. Concluding that, although the risks that are identified have not been registered as accidents, it is necessary to design preventive measures to avoid possible disabling accidents or be classified as an accident at work.

Occupational risks, Manufacture, Occupational Safety

Resumen

El objetivo de esta investigación fue realizar el reconocimiento de los riesgos laborales a los que se encuentran expuestos los operadores del área de producción manufacturera con el fin de buscar posteriormente establecer un programa de seguridad. Realizando la recolección de información por medio de entrevistas semiestructuradas, para posterior recolectar y encontrar la frecuencia de las palabras más recurrentes, con el punto de vista subjetivo. El resultado fue encontrar que los operadores reconocen mayormente los riesgos en la categoría de mecánico al representar un 23.07%, mientras que la categoría del riesgo ergonómico es el menor con 3.84% en conjunto con el químico. Concluyendo que, si bien los riesgos que se identifican no han sido registrados como accidentes, es necesario diseñar medidas preventivas para evitar posibles accidentes incapacitantes o ser clasificados como accidente laboral.

Riesgo laboral, Manufactura, Seguridad Industrial

Citation: CASTILLO-VILLALBA, Rocio Anayeli. Occupational risks in a manufacturing company, a case study in Mexico. Journal Industrial Engineering. 2023. 7-18: 14-20

* Correspondence to Author (e-mail: rcastillov2100@alumno.ipn.mx)
† Researcher contributing as first author.

1. Introduction

According to the type of work, there are different types of occupational risks, also contributing to precarious jobs as it is said in Mexico, as mentioned by the authors Berumen-Rodriguez *et al*. (2020), these risks are due to the conditions to which workers are exposed.

Occupational accidents are a very important issue for all companies, since they can affect the image or reputation of the company; however, in order to avoid or predict these accidents, an analysis of the existing risks in the company can be carried out in such a way that they can be reduced (Dhalmahapatra *et al*., 2022). Risk analysis is said to be the first step to be able to establish preventive measures that allow to have a safety system according to the company (Liu *et al*., 2023), defining the safety system as a tool that allows to inspect and coordinate the risks found in the context of the company.

Although there are defined methods for risk analysis as observed in the regulations applicable in each sector, when starting activities of the company as mentioned in the Federal Labor Law (General Secretariat, 2021), however, there is no specific mention when talking about a company with an existing safety system, so this research aims to give an option on how to identify risks through a descriptive qualitative method, in a Mexican manufacturing company, which allows considering the operators involved in the production processes that are in daily contact.

1.1. Factors related to occupational accidents

Recognizing the factors that are related to accidents is imperative to examine those that may occur in the context of the organization as presented below.

The authors Khoshakhlagh *et al*. (2021) conducted a study on work climate and the relationship between accidents, which he classified as experienced and inexperienced in accidents, also work stress (instability between a person's capabilities and job demand) which is divided into physical and psychological stress, drafting the author that 37% of industrial accidents and injuries is caused by stress, such as injuries suffered by firefighters when exposed to high stress according to Kim *et al*. (2016)

While safety climate is composed of management commitment and competence, and workers' commitment to safety and prioritizing risk acceptance. Some researches resulted that stress influences organizational work and responsibility, therefore, low level of job stress and high social support in the workplace can increase commitment paraphrases the author of Haque and Aston (2016). They conclude that having job satisfaction is a relevant element for stress, while a positive safety climate is related to job satisfaction and risk perception, so the information collected in this study shows great relevance in putting together the effective factors that are related to accidents.

In South Korea, to reduce the factors that can cause falls, slips and injuries, an "intensity analysis" of the root cause is performed, because smart technology and robots are immersed in the activities and sometimes it is difficult to minimize fatal accidents due to the complexity. Identifying the sectors with the highest number of accidents were service, construction and manufacturing industries, for this reason the authors Kang *et al*., (2021) classified the main factors of accidents in the study company in South Korea from these sectors in a "modern root cause representation", where inconsistency, disregard, ignorance, recklessness were recognized as having a higher rate of occupational accidents, while error of judgment, lack of knowledge or awareness, inadequate facility standards, insufficient training, stress, insufficient safety controls in facilities and temporary construction equipment are the best rated, therefore, they suggest promoting an occupational safety and health education plan as well as an equipment lockout system in the context of small and medium-sized enterprises in South Korea.

On the other hand, the authors Kim *et al*. (2021) identified that the main causes of accidents were not stopping the operation of the machine when noticing the presence of workers at the time of maintenance and turning on the equipment as non-routine activities by the company. The accidents also arise from variables identified as fatigue or tiredness causing changes in the use of people's resources, each person has a fatigue limit so that each body may or may not resist fatigue. Fatigue is defined by Norman (1999) as a person's lack of capacity for response or action.

ISSN 2523-0344

Prolonged working hours can cause stress and is related to fatigue, which causes health problems, also according to the study shows that fatigue can be produced by a high relationship between social support and work demand, also showed that stress and social situation at work affect the quality and lack of sleep (Tàpia-Caballero *et al*., 2021).

1.2. Safety program

A safety program implemented in a company will allow to decrease accidents or risks that are present, however, it can also be difficult to implement one, for example, a study proposed by Arbin *et al*. (2021) explain why workers would put resistance to a safety system with subtle actions such as lack of compliance in tasks or safety actions in which it is necessary to contemplate the context of which they are surrounded, sometimes some literature authors summarize that it is the culture of the worker or collective, such as accountability (taking responsibility for actions).

In addition, the aforementioned authors identified the following factors that allow or not the success of a safety program: labor identity (how to act before norms or rules imposed by the company to fulfill the role of worker), facilitation (implement the system of safety and health at work in a way that will not affect production and recognize how to do an activity properly without accidents), visibility (present the system to everyone in the company and accept the opinions to help the system to improve). Concluding that these are the variables that are presented in the resistance on the part of workers when considering implementing a safety system or program (Arbin *et al*., 2021).

2. Methodology to be developed

Using a qualitative method of the descriptive type, semi-structured interviews were applied, which allow the approach and interaction with people having a purpose in the conversation (Ríos Martínez, 2019), the workers of the production area participated, also the direct bosses, the questions asked were: 1) Have they taken any safety course in the company? and 2) What are the risks to which they are exposed?

The purpose of these questions was to make a diagnosis of the safety situation and identify the risks to which they are exposed and whether they recognize them as such

3. Sample

The research was carried out in a metal-mechanical company that manufactures automobile parts, in the production areas of cementing, stamping, welding, maintenance and stamping, with a total of 57 people, including operators and supervisors in each area.

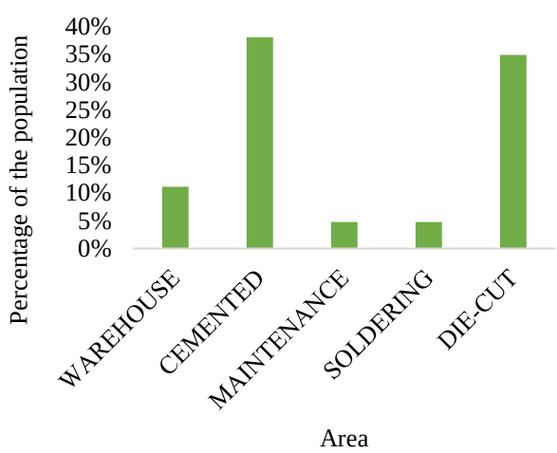
4. Data Collection

Data were collected on the company, such as the number of people in each area. The use of semi-structured interviews is a tool in qualitative studies (Merriam & Tisdell, 2015).

The design of the semi-structured interviews will help to review the understanding of the immediate bosses about safety issues, as well as to recognize the awareness they have about the risks they are exposed to, since the safety measures were established more than 10 years ago. The answers were counterbalanced to find a standard as suggested by author Yin (2018) and thus be able to define the variables applicable to the company on the topic of safety.

5. Results

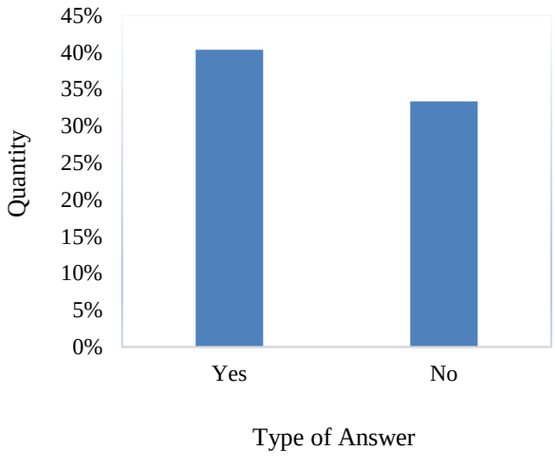
The number of people that each production area has is shown in Graph 1, for which 42% of the sample is in the cementing area, while 39% is in the die-cutting area.



Graph 1 Graph of the number of people in the production área
Source: Own Elaboration, data provided by the company, 2022

It can also be observed that the area where there are fewer personnel is in welding and assembly, therefore, the high production processes where more attention must be paid is where work is performed on heavy machinery.

For the answer to the first question, regarding any course taken on the subject of safety, Graph 2 below shows that only two responses were considered:



Graph 2 People who have taken a safety course.
Source: Own Elaboration, 2022

As can be seen in the graph, 40% of the participants confirmed having taken some safety course, however, those who responded negatively contain people with a seniority of 5 to 10 years, because in the interview they responded that they did not perceive that the training taken was related to the safety of their activities.

The topics that most of the personnel mentioned having seen were: how to handle a forklift and self-safety.

Below is a diagram showing the answers given by the operators to question number 2, What are the risks to which they are exposed, this from an empirical point of view, the answers are shown in Figure 3 below:

Figure 3 Risks identified by the workers
Source: Own Elaboration, 2022

In the following table, according to the literature, it is advisable to classify them by mechanical, physical, ergonomic and chemical risk, as shown below:

Risk category	Risk identified by workers	Frequency %
Physicist	Burns	9.61%
	Cuts	11.53%
	Falls of material or tools and slipping falls	25%
Ergonomic	Injuring your back	3.84%
Chemist	Solvent splash on the face	23.07%
	Eye irritation from chemicals	3.84%
Mechanic	Crushing of hands and fingers	23.07%

Table 1 Classification of risks identified by personnel
Source: Own Elaboration, 2022

Then the above indicates that the risks identified by the operators in the company are in the category of physical risk followed by chemical risk, having 2 or more risks mentioned by the operators, according to the interview responses most of the workers recognize these risks because, at some point they were present in an accident or some unfortunate event happened to them.

Also the risk that was less identified, the ergonomic risk, according to the interviews, is due to the fact that few people load boxes or heavy material, since they are in the warehouse area. In addition to using support equipment such as skates or forklifts.

ISSN 2523-0344

6. Discussions

To observe how the process of risk perception is, it should be taken into consideration that it starts with the interaction of people and the activities they perform daily (Castillo, 2013), agreeing with what Znajmiecka Sikora & Sałagacka (2022) mentions, the older the worker is, the more positive attitudes to take care of themselves increase due to the acquired experience.

The interviews conducted were structured in two parts, one focused on recognizing how they identify or understand a risk in their area, due to the fact that risk perception is an open process that can come from one's own knowledge or character, therefore, the perception has to consider the human being as a person who has faith, stereotypes, qualities and own stimulations as mentioned by Alonso Morillejo & Pozo Muñoz (2002). While the second part of the interview is to recognize if the training provided by the company gives them a different perception of security.

The way in which each person understands risk is very important because this is how self-care will be sought, in addition, operators perceive that a risk is "when we put our person and health at risk with the activities we do" (Operator 38, 2022), which is very close to the definition mentioned in the Federal Labor Law (General Secretariat, 2021).

Risk perception, according to Vera Calzaretta *et al*. (2010) is found at two levels: the first, empirical, which arises from an experience of risk and the second, natural, from the social point of view, i.e., that which we are taught as dangerous since our childhood. For this reason, the risks identified in the area (Figure 3) by the workers are perceived and understood from the empirical point of view, since they arise from the experience of each individual, because they have had the experience of seeing an accident or having suffered one.

The concept of risk perception, as mentioned above, has a wide field, since it is studied from various points of science (Carbonell-Siam & Torres-Valle, 2010). For this reason, this work was carried out from the subjective risk, considering the point of view of each of those involved in the area.

Likewise, it is said that the perception of risk, although it is different for men and women, the existence of theories that try to understand this interprets that people are exposed to risks for two reasons: the first is an objective such as satisfying a need, the second can be related to a pleasurable stimulation.

The way of receiving training is superficial according to the response of the operators, but training with veteran personnel to learn good practices and avoid accidents, is only a part not contemplated, since the operators do not perceive this training as a safety issue coinciding with what the authors Goodbrand e*t al*... mention, (2021), it is also worth mentioning that incidents in a company are always latent, due to working with the human factor, for that reason the author Ahumada Villafañe *et al*. (2019) also supports understanding and investigating through interviews with personnel to recognize the risk and their point of view.

7. Acknowledgement

We are grateful for the support from CONAHCYT that made this possible, as well as to the University of the National Polytechnic Institute, UPIICSA, for its approach to the company and for being able to collect the information.

8. Conclusions

The risks obtained from an empirical point of view based on the experience of each operator, made it possible to identify those that, despite having preventive measures in the operational area, the operators continue to be aware of in their activities.

Having the point of view of the workers will also allow them to feel heard so that they can express those incidents or accidents that, because they are minimal, are not considered dangerous; however, it is necessary to take measures, as is the case with the splashing of solvents on the face, which, although they do not exist in the company's records, have happened and adequate measures have not been taken. This work opens the way for a more in-depth study of each risk identified and thus avoid incidents that could later become disabling accidents.

ISSN 2523-0344

In addition, a deficient training on safety issues specific to the activities performed was noted, since, although several operators have been trained, they do not see the relationship between safety and their work.

References

Ahumada Villafañe, I., Palacio Angulo, J., Posada López, J., & Darío Orjuela, I. (2019). PERCEPCION DEL RIESGO LABORAL EN TRABAJADORES OPERATIVOS DEL SECTOR METALMECÁNICO. *Revista Científica Multidisciplinaria*, *4*(1), 49–59. https://doi.org/https://doi.org/10.25214/27114406.939

Alonso Morillejo, E., & Pozo Muñoz, C. (2002). La percepción del riesgo en la prevención de accidentes laborales. *Apuntes de Psicología*, *20*, 415–426. https://apuntesdepsicologia.es/index.php/revista/article/view/1383

Arbin, K., Frostenson, M., Helin, S., & Borglund, T. (2021). Explaining workers' resistance against a health and safety programme: An understanding based on hierarchical and social accountability. *Safety Science*, *136*. https://doi.org/10.1016/j.ssci.2020.105131

Carbonell -Siam, A. T., & Torres -Valle, A. (2010). Evaluación de percepción de riesgo ocupacional. *Ingeniería Mecánica*, *13*(3), 18–25. http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1815-59442010000300003

Castillo, S. (2013). Percepción Social del Riesgo Laboral. *Revista COPÉRNICO*, *17*, 15–21. http://bdigital.ula.ve/storage/pdf/copernico/n17/art03.pdf

Goodbrand, P. T., Deng, C., Turner, N., Uggerslev, K. L., Gordon, J., Martin, K., & McClelland, C. R. (2021). Exploring safety knowledge sharing among experienced and novice workers. *Journal of Safety Research*, *79*, 125–134. https://doi.org/10.1016/j.jsr.2021.08.013

Kang, Y., Yang, S., & Patterson, P. (2021). Modern Cause and Effect Model by Factors of Root Cause for Accident Prevention in Small to Medium Sized Enterprises. *Safety and Health at Work*, *12*(4), 505–510. https://doi.org/10.1016/j.shaw.2021.08.002

Khoshakhlagh, A. H., Yazdanirad, S., Hatamnejad, Y., Khatooni, E., Kabir, S., & Tajpoor, A. (2021). The relations of job stress dimensions to safety climate and accidents occurrence among the workers. *Heliyon*, *7*(9). https://doi.org/10.1016/j.heliyon.2021.e08082

Kim, S., Lee, J., & Kang, C. (2021). Analysis of industrial accidents causing through jamming or crushing accidental deaths in the manufacturing industry in South Korea: Focus on non-routine work on machinery. *Safety Science*, *133*. https://doi.org/10.1016/j.ssci.2020.104998

Merriam, S. B., & Tisdell, E. J. (2015). *Qualitative research* (JOSSEY-BASS, Vol. 4). https://books.google.com.mx/books?id=omQdCgAAQBAJ&pg=PA219&source=gbs_selected_pages&cad=3#v=onepage&q&f=false

Secretaría General. (2021). *Ley Federal de Trabajo*. Diario Oficial de La Federación. https://www.diputados.gob.mx/LeyesBiblio/pdf/LFT.pdf

Tàpia-Caballero, P., Serrano-Fernández, M. J., Boada-Cuerva, M., Boada-Grau, J., Assens-Serra, J., & Robert-Sentís, L. (2021). Age, gender, personality, burnout, job characteristics and job content as predictors of driver fatigue. *International Journal of Occupational Safety and Ergonomics*. https://doi.org/10.1080/10803548.2021.1991672

Vera Calzaretta, A., Varela Valenzuela, L., & Macía Sepúlveda, F. (2010). El Estudio de la Percepción del Riesgo y Salud Ocupacional: Una Mirada desde los Paradigmas de Riesgo. *Ciencia y Trabajo*, *35*, 243–250. www.cienciaytrabajo.cl

Yin, R. K. (2018). *Case study research and applications design and methods* (sexta). SAGE Publication, Inc. https://books.google.com.mx/books?id=6DwmDwAAQBAJ&pg=PT94&source=gbs_selected_pages&cad=3#v=onepage&q&f=false

Znajmiecka Sikora, M., & Sałagacka, M. (2022). Analysis of the relationship between psychological gender and risk perception style and attitudes towards safety in a group of women and men. *International Journal of Occupational Safety and Ergonomics*, *28*(1), 364–375. https://doi.org/10.1080/10803548.2020.1760527

ISSN 2523-0344

Article **Journal Industrial Engineering**
June 2023, Vol.7 No.18 21-33

Method to detect faults in the rotor squirrel cage with low load in permanent state using DWT

Método para detectar fallas en el rotor de jaula de ardilla con baja carga en estado permanente usando DWT

MARTÍNEZ-GARCÍA, Irving I.†* & PEÑA-CABRERA, J.Mario

Universidad Nacional Autónoma de México LEIA 4.0, FI-IIMAS, CDMX, México

ID 1st Author: *Irving I., Martínez-García* / **ORC ID**: 0000-0002-6709-4748, **CVU CONAHCYT ID**: 646178

ID 1st Co-author: *J.Mario, Peña-Cabrera* / **ORC ID**: 0000-0002-0104-6559, **CVU CONAHCYT ID**: 111601

DOI: 10.35429/JIE.2023.18.7.21.33 Received January 20, 2023; Accepted June 30, 2023

Abstract

Although there are several methods that can be used, the Continuous Wavelet Transform and its discrete version have demonstrated their ability to work with these signals. This article presents a new method to help detect early faults in the rotor squirrel cage of induction motors no-load and operational state, specifically in bars and rings. Using three techniques on the whole as it is the motor current signature analysis (MCSA), discrete wavelet transform (DWT) and multi-resolution analysis (MRA) with a decomposition tree reduced and apply a suitable index that determines the condition of the rotor. A brief description of the case study on which the research carried out is based is offered, which is used here successfully to generate a new alternative to determine the condition of the rotor squirrel cage. The performance of the results is get from the experimentation carried out and determined through comparison between the DWT conventional analysis and the new method, also exposing a brief comparison using the fourier transform. This new method reduces the uncertainty when performing the rotor diagnosis and improves the accuracy to differentiate the condition where it is.

DWT, Fault detection, Induction motor

Resumen

Aunque existen varios métodos que se pueden utilizar para el análisis de motores de inducción, la Transformada Wavelet Continua y su versión discreta han demostrado su capacidad para trabajar con estas señales. Este artículo presenta un nuevo método para ayudar a detectar fallas tempranas en el rotor de jaula de ardilla de motores de inducción sin carga y en estado operativo, específicamente en barras y anillos. Utilizando tres técnicas en su conjunto como lo es el análisis de firma de corriente del motor (MCSA), la transformada wavelet discreta (DWT) y el análisis multiresolución (MRA) con un árbol de descomposición reducido y aplicando un índice adecuado que determina el estado del rotor. Se ofrece una breve descripción del caso de estudio en el que se basa la investigación realizada, el cual se utiliza aquí con éxito para generar una nueva alternativa para determinar el estado del rotor de jaula de ardilla. El rendimiento de los resultados se obtiene a partir de la experimentación realizada y se determina mediante la comparación entre el análisis DWT convencional y el nuevo método, exponiendo además una breve comparación utilizando la transformada de Fourier. Este nuevo método reduce la incertidumbre a la hora de realizar el diagnóstico del rotor y mejora la precisión para diferenciar el estado en el que se encuentra.

TDW, Detección de fallas, Motor de inducción

Citation: MARTÍNEZ-GARCÍA, Irving I. & PEÑA-CABRERA, J.Mario. Method to detect faults in the rotor squirrel cage with low load in permanent state using DWT. Journal Industrial Engineering. 2023. 7-18: 21-33

* Author's Correspondence (e-mail: numeros_complejos@hotmail.com)
† Researcher contributing as first author.

Introduction

There are many techniques and monitoring methods used for the diagnosis or evaluation of the state of induction motors [1-3]. The most used technologies and techniques are vibration analysis, thermography, ultrasound, current and voltage analysis, better known as MCSA [4-6], latter is most used due to its characteristics, since it is a non-invasive technique, until certain point practical and relatively simple to acquire the study signal.

However, when the type of electrical signals used for current analysis in electric motors is explored, an open field of research appears to find new methods and tools that are better adapted to their analysis, so far there are several methods that use the Wavelet Transforms in their discrete version that have demonstrated the ability to work with signals that can be generated from the use of faulty A.C. induction motors as [7-10].

There are various works that address the detection of faults in induction motors and specifically in the rotor, but nevertheless many work consider detection and classification interchangeably, it seems that both must be necessarily linked when the study of the faults of motor is carried out, it must be taken into account that detection is the action of capturing, noticing or perceiving the presence of a particular signal related to the failure and the classification is based on this so that applying tools such as support vector machines (SVM) [11], fuzzy logic [12], arrangements of neural networks (NNA) [13], [14] among many others is carried out, consequently if the method or tool used for detection is not adequate, uncertainty will always exist to a lesser or greater extent.

In this work was developed a new method that is based on the apply of the Discrete Wavelet Transform and the analysis of permanent stator current, with motor no-load. It focuses on study of the coefficients resulting from decomposition through of high-level wavelet signals in permanent or stable current, as a way of detecting the presence of left sideband component from multiresolution analysis. Energy of these coefficients shows a clear difference when a breakage of the rotor ring or bar has occurred.

The comparison of analysis results of signal has been made using the tools Python and Matlab, first comparison with the results of the analysis of signal using a classic tool as Fourier Transform was made, second with the Discrete Wavelet Transform was made, in this last the results of the usual or conventional analysis is made compared the method developed with a pre-processing specific to optimize the analysis and detect faults early induction motors rotor.

The experiments with a squirrel cage induction motor on a test base built for diagnostic purposes have been carried out. A data acquisition system based on an embedded board and an analog-to-digital converter module with programmable gain and high resolution was developed. It is very important given that the high resolution will allow detection of failures with a reduced decomposition tree. An important advantage of this tested method is that it leads to a correct diagnosis in some times where Fourier Transform approach does not provide as accurate results, such as no-load or low-load machines, this method improves the ability to distinguish between rotor states and makes the difference in their condition obvious comparing against usual DWT analysis, where in different works, only the selection of mother wavelet used or sampling frequency of signal changes for application of the decomposition tree example of this can be seen in [15-18].

.

Case study: method basis

The extensive study of induction motors has yielded multiple findings on its operation, in this work we focus on the operation and characteristics of rotor of squirrel cage induction motors, within the various studies of this area of motor, it has been shown that broken bars produce induced frequency components in the current spectrum in $[(1 \pm 2s) * f_1]$, where "s" is the slip and "f_1" is the supply frequency or fundamental frequency.

It has been known since the 1920s that an asymmetrical rotor winding, whether in a three-phase cage or slip-ring induction motor, will induce a voltage in the stator winding at a frequency of $f_1 * (1 - 2s)$ Hz and, therefore, conduct a current at that frequency in the stator.

ISSN 2523-0344

The cyclical variation in current caused by a broken rotor bar produces a torque variation at twice the slip frequency and this produces a speed variation that is a function of driveshaft inertia. This normally reduces in the magnitude of the current component $f_1 * (1 - 2s)$ and a new current component appears in $f_1 * (1 + 2s)$ and its magnitude can be improved by modulating the third harmonic flow of time in the stator. The greater the inertia of the drivetrain, the greater the resistance to oscillation of torque and speed at $2sf_1$ and therefore the smaller the magnitude of the upper sideband at $+2sf_1$ compared to the lower sideband $-2sf_1$ around *f*, the supply or fundamental component. Therefore, the cage winding breaks produce two sidebands at $\pm 2sf_1$ around *f*, and given by the aforementioned equation, the magnitude of the supply frequency component can be 20 to 1000 times greater than the magnitude of the sidebands according to [19].

In summary, electromagnetic field anomalies in the air gap create sideband harmonic components in the stator current spectra. It is here in the stator winding which is traversed by a balanced system of currents (three-phase current) that gives rise, because of the Ferraris Theorem, to a rotating magnetic field whose speed is known as synchronism speed and is in Hz is calls n_1, this is calculated from the line or fundamental frequency f_1 of the stator currents and the number of even poles by the following quotient.

$$n_1 = \frac{60 f_1}{p} \tag{1}$$

In the rotor, which is the rotating part made up of an axis or central arrow with a series of laminations in a block or package with slots in which a series of conductors known as closed bars with a pair of rings at their ends are fused that short-circuit each busbar. In motors with a squirrel-cage rotor, the rotating field created in the stator generates electromotive forces (e.m.f.s.) in the rotor winding and when this is short-circuited, currents appear that generate a magnetic field, which when interacting with the rotating field of the stator move it at a speed close to but below the synchronism known as the mechanical speed of the motor (*n*), in such a way that the general expression for this type of machine is given by

$$f_2 = f_1 - \frac{n * p}{60} \tag{2}$$

The relative difference between the stator (synchronous) and rotor (mechanical) magnetic flux speeds is known as "slip" (*s*). Is called slip s to following relationship

$$s = \frac{n_1 - n}{n_1} = \frac{\Omega_1 - \Omega}{\Omega_1} \tag{3}$$

in Hz and radians respectly, substituting equation (1) in (3) it is expressed as follows

$$s = \frac{\frac{60 * f_1}{p} - n}{\frac{60 * f_1}{p}} \tag{4}$$

Now the conductors of rotor winding (bars) see the field originated by the stator winding rotate with a relative speed n_2 (value of the speed of the rotating field, synchronous speed, from the point of the bars), which can be expressed as:

$$n_2 = n_1 - n = s * n_1 \tag{5}$$

Consequently, since this magnetic field has *p* pairs of poles, in one minute a rotor driver has seen n_2*p magnetic cycles pass in front of him (each pair of poles makes up a cycle of the wave of magnetic field in air gap, which is repeated in the next pair of poles and so on in all the pairs of poles of the machine). Each magnetic cycle induces a period of the e.m.f. time wave when turning ahead of a rotor driver. This causes the rotor phases to induce an e.m.f.s whose frequency is $n_2 * p$ cycles per minute, that is a frequency f_2 that measured in Hz (cycles per second) can be calculated as:

$$f_2 = \frac{n_2 * p}{60} = s\left(\frac{\frac{60 * f_1}{p} * p}{60}\right) \tag{6}$$

Then, taking relationship (1) into account, it can be deduced from the above that there is a frequency in the rotor phases that is expressed according to the following relationship.

$$f_2 = s * f_1 \tag{7}$$

Fourier Transform

In signal analysis there are many tools that can be used, among which the Fourier Transform [20-24] or stands out and is also one of the most common, thanks to its relative simplicity of use application and its ability to deliver a representation of the frequency content that a certain signal has, however, due to the limitations of said tool, new tools have been developed that allow an analysis of the signals from another perspective as the STFT [25], [26] due to the need to analyze signals that do not behave in a stationary way and/or that present abrupt changes in very small intervals, another one of these tools is the Wavelet Transform as mentioned in [27-35]. To better understand these signal analysis tools and observe how WT eliminates the limitations of FT, they are presented next.

Beginning with the Fourier Transform, the purpose of the mathematical transformations that apply to the signals is to get more information from them than that which can be extracted from the signal in time, the Fourier Transform allows a signal to be decomposed into its components sinusoidal and cosine waveforms of different frequencies and amplitudes, it can be seen roughly as a mathematical tool or technique to transform the point of view of the signal from a time basis to a frequency basis, as illustrated in figure 1.

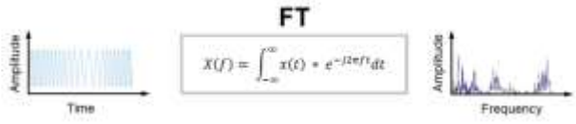


Figure 1 Fourier Transform

In most cases, the analysis by Fourier Transform is useful, however when passing a signal to the frequency domain, the information regarding time is lost, because when a signal is observed to which the Transformation of Fourier, it is impossible to determine exactly when a given frequency occurs or is present (in the time domain).

Discrete Wavelet Transform

Wavelet Transform applied to a series of numerical data makes it necessary to implement a Discrete Transform [36-42]. Considering the Wavelet Transform of a continuous signal $x(t)$, but with discrete translation and scaling parameters *a* and *b*. A natural way to sample the parameters *a* is by using logarithmic discretization of the scale *a* and binding it to the step size of *b*, that is moving in discrete steps to each location of b which is proportional to the scale *a*. This discretization of the Wavelet has the following form:

$$\psi_{m,n}(t) = \frac{1}{\sqrt{a_0^m}}\,\psi\left(\frac{t - nb_0a_0^m}{a_0^m}\right) \tag{8}$$

where $m, n \in \mathbb{Z}$ control scaling and translation respectively, a_0 is the fixed expansion step size greater than 1 and b is the location parameter that must be greater than zero. From equation (8), the translation step size $\delta b = b_0 a_0^m$ is directly proportional to the wavelet scale a_0^m. Therefore, the Wavelet Transform of the continuous signal *x*(t) using discrete Wavelets of the form (8) is given by:

$$\mathrm{T}_{m,n}x = \int_{\mathbb{R}} x(t) * \frac{1}{a_0^{m/2}}\psi\,(a_0^{-m}t - nb_0)dt \tag{9}$$

The most common values of a_0 and b_0 are 2 and 1 respectively, the logarithmic scaling in powers of two of the step sizes of translation and dilation is known as dyadic mesh array. Substituting $a_0 = 2$ and $b_0 = 1$ in equation (8), the wavelet of the dyadic mesh is written as:

$$\psi_{m,n}(t) = \frac{1}{\sqrt{a_0^m}}\psi\left(\frac{t - nb_0a_0}{a_n^m}\right) \tag{10}$$

First approach: Analysis based on the Fourier transform

First analysis was carried out with the Fourier Transform, analyzing the resulting spectrum of the study signal before and after the application of the one-sideband signal preprocessing and conditioning system (SCPS-1SB) figure 2, with a healthy motor. Which has as its main element a special filter of specific characteristics, or Band Pass-Filter of specific selection exclusive (FPB-ESE) antialiasing.

ISSN 2523-0344

Specifically designed to contribute to the detection of signals near to the line frequency in order to more easily detect faults rings or bars.

Figure 2 SCPS one-sideband

In conventional analysis with FT, to detect frequency of broken bars and rings during steady-state operation, a fast Fourier Transform is performed on the study signal. The frequency amplitude of broken bars and rings is more noticeable when the load or the number of broken bars increases and as the motor load approaches the full load condition, the motor speed is below motor speed without load so the frequency of broken bars and rings is more separated from the line frequency, making it easier in this condition to locate and identify the frequency of broken bars and rings.

On the contrary, if motor load is near or in the unloaded condition, frequency of broken bars and rings is very close to the line frequency, making it very difficult and even indistinguishable, and therefore the condition broken bars cannot be detected, and under any other load condition, the amplitude of the broken bars and broken ring frequency is very small compared to that of the line frequency, requiring a high-speed analog-to-digital converter or high resolution, in this work, high resolution was chosen instead of high sampling as in most of the works that were reviewed and carried out up to now.

Figure 3 shows spectrum of the raw signal healthy versus the spectrum of signal applying the preprocessing to the SCPS-1SB signal healthy. In this comparison we can see that there are slight differences in magnitude between the two spectra because of the filtering so close to the line frequency that was carried out, although no difference that could be of importance is observed, the differences that are observed are due to the work that the signal processing. In figure 4 shows comparison of spectra of the healthy signal and with failure, both with signal processing, in which it is possible to notice a greater difference in signal level, but at very low levels.

This makes it difficult to differentiate between the states of healthy and failed motor using only the spectra, getting worse much with variable loads, since line frequency is still too high, eclipsing the signals of interest.

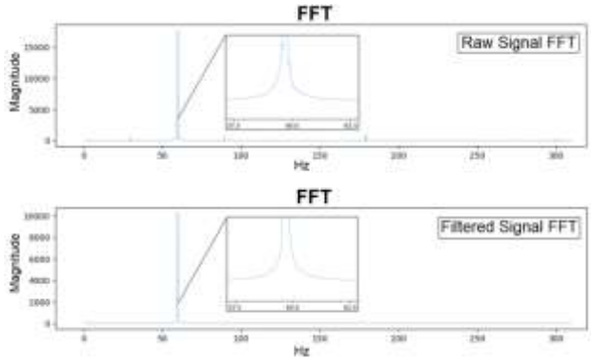


Figure 3 Spectrum of signal FT without and with SCPS-1SB

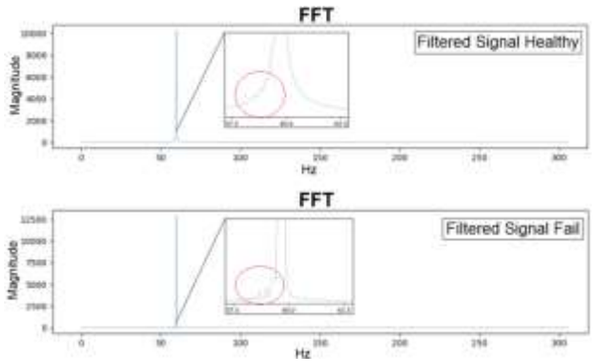


Figure 4 Spectrum of signal FT healthy vs fault.

Second approach: Analysis based on the Discrete Wavelet transform

Second analysis was performed with the Discrete Wavelet Transform 1-D. After performing the signal conditioning is done preprocessing where the SCPS-1SB is applied, the next step is the application of the signal to the decomposition tree or multi-resolution analysis based on the transform algorithm fast wavelet using matlab, for this some aspects must be considered, the first is the choice of a mother wavelet in which the correlation of this with the study signals must be considered, in the same way the necessary decomposition levels must be calculated, the number of these will result according to the sampling frequency used, this can be done by means of an expression which is used with some variations by as shown in [10], [14].

ISSN 2523-0344

There are multiple variations of the equation to determine the limit of decomposition levels according to the main purpose and the specific data for this work. In this particular case, the line frequency is 60 Hz according to our geographical region and the sampling frequency is 720 Hz, low compared to that used in other works but it does not prevent the effectiveness of method, which is result of operation of data acquisition module and board with embedded system used.

The choice of mother wavelet is of the utmost importance, in this study wavelet Daubechies-44 (db44) was used, and although due to its level it requires a large computational load, its good work has been demonstrated in the detection of failures in broken bars and rings in induction motors compared to other [10], [14], [35]. It is the one that are selected as the mother wavelet, since they is provide a more precise detail signal with lower harmonics since as the wavelet is of a higher level, it is located less in time and oscillates less due to the dilation nature of wavelet transform, this means that at a higher level it behaves like a filter more ideal.

The equation chosen to calculate the levels of decomposition or branches is:

$$n + 1 = int\left(\frac{log\left(\frac{f_s}{f_L}\right)}{\log(2)}\right) + 1 \qquad (11)$$

The result that calculation gave us using suitable sampling frequency and line frequency gave us a decomposition tree made up of 4 levels, one thing to remember is that the decomposition tree has a decimated dyadic structure, this means In other words, for each level that increases the samples are reduced in powers of two, this type of structure optimizes the characteristics of the system since it avoids having redundancy in the output data (coefficients C_A, C_D).

This can be seen in the multi-level or multi-resolution decomposition tree figure 5, in which the four levels are shown with the respective outputs of the detail coefficients and the output for level four of the approximation coefficients.

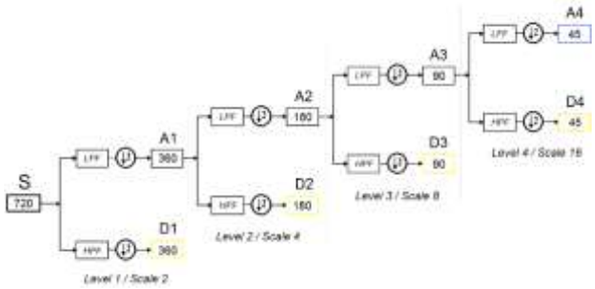


Figure 5 Multiresolution decomposition tree.

This method is based on three tools which are:

Techniques applied in the method		
MCSA - Motor Current Signature Analysis	AWT – Analysis wavelet transform	AMR - Analysis Multiresolution
Pre-processing		
Post processing		

Diagram 1 Techniques and processing

Experimental results.

For validation of method, several tests were carried out with a 4-pole 2Hp squirrel cage induction motor. The motor was initially tested in a healthy state, later proceeded ring and rotor bar breaks were performed in a laboratory; the separation was made in the ring's width and the bar with an approximate thickness of 1mm. After finishing the tests in a healthy state, the motor was disassembled to gain access to the rotor and be able to carry out in the failure's simulation, material was artificially removed to generate the break in the ring and the bars (Fig. 7) The data on study's motor nameplate are: brand: WEG, model: 00218ET3EM145TCW, Star connection, nominal voltage: 230 V, nominal primary current: 5.52 A, nominal power: 2Hp, 4 individual poles, nominal speed: 1755 rpm, service factor: 1.25, Insulation class: F and number of rotor bars: XX. The figure 6 shows the diagram of acquisition and processing of signal.

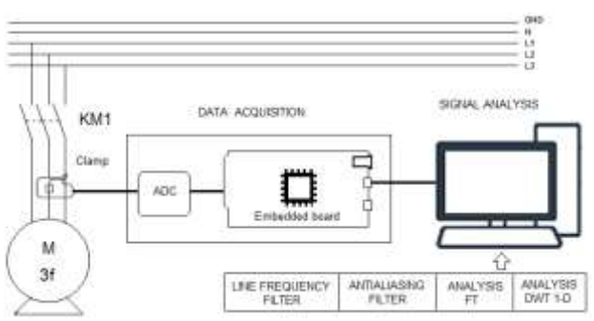


Figure 6 Data acquisition and processing

Figure 7 Tool and ring and bar failure simulation, broken rotor

To select the line where the current data would was get, an initial comparison was made in the three phases, taking into account as selection criterion which was the most stable and with the least variations between tests, was selected the phase or line number 2, for having the greatest stability and least variation between tests. In this, the primary current was measured during permanent state for the different cases tested, for this condition the samples were taken after 10 seconds of starting the motor. To capture data, an analog-to-digital converter was used with a sampling frequency of 860 samples/s theorist with programmable gain and 16-bit resolution. To carry out the acquisition of the current signal, Python was used and the analysis was carried out with the DWT, it was done with MATLAB. A 4-level decomposition was performed using the mother wavelet Daubechies-44 for analysis. Table I shows frequency bands corresponding to high-order wavelet signals resulting from the analysis, according to sampling rate used for tests.

Table I shows bandwidth with which each level remains for details or high-frequency signals, as well as for approximations or low frequency signals. In this table, It can be seen that our area of interest focuses mainly on the level four of details, since in this they will meet the signs of interest.

Level	Approximations	Details
1	A1 : [0 , 360]	D1 : [360 , 720]
2	A2 : [0 , 180]	D2 : [180 , 360]
3	A3 : [0 , 90]	D3 : [90 , 195]
4	A4 : [0 , 45]	**D4 : [45 , 90]**

Table 1 Frequency bands in hz for twd with f_s=720 Hz

Analysis and comparison of the signals

Figures 8 and 9 show analysis multi-resolution of the signal no-load state of motor, where in the first (figure 8) the levels of the raw signal or without process are shown, according to the amount of data and algorithm that Matlab uses, the decomposition levels should be 13, having several levels that are not relevant for the study of the signals that indicate rotor failures, or of interest (d6-d13), this can be seen clarity in figure 9 since after applying the SCPS-1SB, where only the signals that would indicate the failure in the rotor of the squirrel cage induction motor appear, these levels lack of any variation in the signal. Thus we can see that an analysis can be carried out with fewer levels, more stable and without variations after the application of SCPS-1SB without losing the characteristics or signals of our interest for the detection of failures, and be able to differentiate with total clarity the moments of inflection.

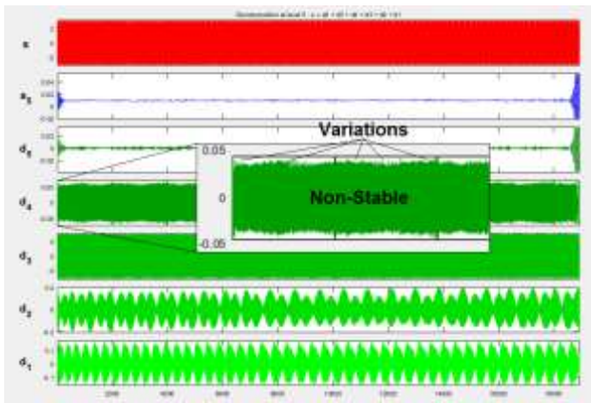


Figure 8 Raw signal no-load motor, figure shows the decomposition of 5 levels showing variations in the last three levels

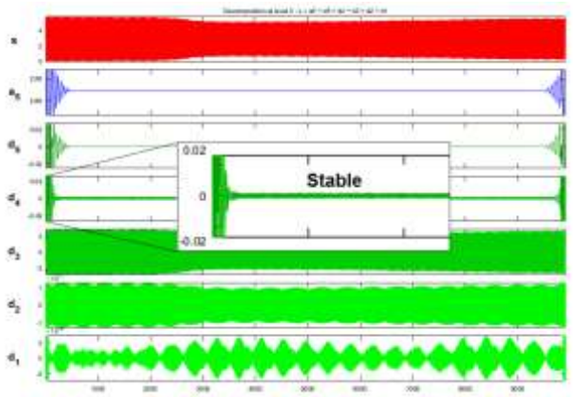


Figure 9 Signal SCPS-1SB no-load, figure shows the decomposition of 5 levels without variations in the last three levels

This small difference and elimination in the oscillation of the resulting signals is a great advance of the utmost importance since for analysis of the signals of faults a small difference can cause an increase in their energy, and if don't have stability, this could be inconvenient since the variations cause uncertainty and mistakes when differentiating the state where motor is located, provoking diagnoses doubtful or wrong.

The index used to determine the state of rotor is governed under the condition of having a stable signal, when applying the SCPS-1SB the graphs of the different levels of coefficients show that a smaller number of levels is required for analysis of signal, from here the analysis is carried out with fewer levels giving way so to comparison between the resulting of signals in a healthy and with failure state.

Method for detecting faults

The tests show that Discrete Wavelet Transform performs a more adequate analysis for this type of signals caused by failures in rotor of induction motors carried out, getting results with greater precision due to the conditioning and preprocessing of signal, increasing the accuracy when diagnosing the condition of motor however the results of analysis with conventional method are not as noticeable or evident by the variations present in the resulting signal, variations that are reflected in the energy's magnitude of *f* the coefficients, in proposed method to detect faults in bars and rings of the squirrel-cage rotor certain features stand out to be able to detect with failures more clearly and easily to remove the uncertainty due to low visible difference but enough between motor states.

Figure 10 of signals of output SCPS-1SB no-load with fault motor and signal of output SCPS-1SB no-load without fault motor clearly show that there is a notable difference in the levels of the resulting coefficients at the level of interest (cD4), the level at which where are the signs related to failures in the rotor of induction motors, due to the special treatment that was done to the signal to it analysis, since the sideband method is used to detect faults.

To improve the results get and avoid the deviation in the value of the result of the coefficients, a statistical study of the resulting signals was made and a statistical analysis was carried out, where did it began debugging the signal considering only the values where the convolution of the signals completely overlap and the values outside the limit of the signal are not considered. Following this concept, it goes one step further and the study and analysis was carried out, reducing to the resulting signal 14 points less in both ends of the signal to reduce variation and improve accuracy of results.

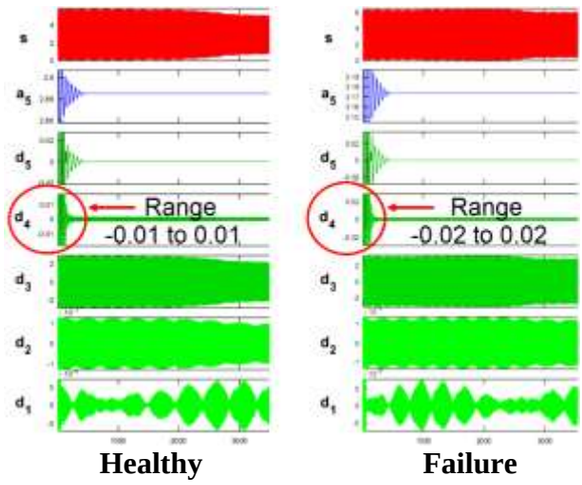


Figure 10 Levels at the output of the SCPS-1SB, figure on the left side shows the analysis of the motor signals without fault in no-load, the figure on the right side shows the analysis of the motor signal in no-load with fault

The calculation and comparison of energy of the coefficients was made where energy 1 is calculation of complete signal, energy 2 is calculation of the signal with the elimination of the length of kernel of convolution and energy 3 results from the signal removing the length of Kernel and 14 extra points. These points were taken according to the results of the graphs because of, the tests and analysis carried out, the basis that was taken was realization of an average of the results of energy of each test carried out, calculated with MATLAB the results.

Figure 11 shows comparison of the signals resulting from the level of interest (cD4) for detection of failures in the rotor of induction motors, it shows the graphs of complete signal, the signal with the elimination of kernel length of the convolution and the signal removing kernel length and 14 more points.

ISSN 2523-0344

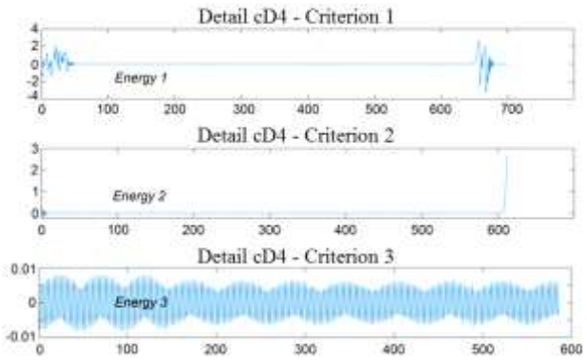


Figure 11 Coefficient signals level 4 (cD4)

Table II shows results of deviation get of the tests results indicating precision which we have an average deviation of 37% for original signal results, an average deviation of 56% for signal with elimination of kernel length and an average deviation of 13% of signal eliminating Kernel length and 14 points, these results clearly show an improvement in stability and precision of method regarding the usual analysis, as well as being more exact in differentiation of motor no-load states.

# Test	% Energy 1	Abs	% Energy 2	Abs	% Energy 3	Abs
1	96.460	**3.539**	120.765	**20.765**	75.497	**24.502**
10	73.245	**26.754**	5.183	**94.816**	126.298	**26.298**
20	115.819	**15.819**	113.698	**13.698**	103.014	**3.014**
30	72.492	**27.507**	93.596	**6.403**	64.207	**35.792**
40	40.054	**59.945**	39.009	**60.990**	109.364	**9.364**
50	107.083	**7.083**	125.068	**25.068**	93.842	**6.157**
60	181.603	**81.603**	202.880	**102.880**	117.831	**17.831**
70	69.910	**30.089**	6.686	**93.313**	98.075	**1.924**
80	112.711	**12.711**	139.432	**39.432**	102.309	**2.309**
90	186.287	**86.287**	206.161	**106.161**	116.420	**16.420**
100	44.3304	**55.669**	47.518	**52.481**	93.136	**6.863**

Table 2 Absolute deviation of the signal in %.

Gratitude

IIMAS, DISCA LEAI4.0 section and FESC C-4, LIME-IV, UNAM, is thanked support for to carry out this work.

Financing

This work has been financed by CONAHCYT with the support of a scholarship under CVU number 646178.

Conclusions

There are multiple methods and tools for the analysis of rotor failures, Fourier Transform is a powerful tool for the analysis of the line current signature in squirrel cage induction motors, however it is not the most appropriate since it does not behave in the best way in the analysis of resulting signals of processes where there is a variable load with sudden changes in a short time, as well as in signals where the motor has the minimum requirement having a low load, in this paper this last point is addressed.

In this paper, a novel and specific method for the detection of broken rotor rings and bars in induction motors no-load and in steady state is presented, an extreme condition where the detection of faults is the most difficult and very few works have studied. The method is based on specific treatment performing an adequate conditioning of the signal, designing and calculating a special filter, which performs three functions: first, it is responsible for filtering the line or fundamental frequency to avoid eclipsing signal that indicate a fault, as well eliminate signals that are not necessarily a sign of failure because of harmonics and for another, it performs an anti-aliasing, besides to restricting the window to a specific band where possible rotor failures are found only, ensuring its operation, filter job of this filter is based on the frequencies that have been extensively studied and that are known with theoretical certainty to be indicative of damage to the rotor, this special filter with the elements in charge of signal acquisition and preprocessing is called the signal conditioning and preprocessing system one-sideband (SCPS-1SB). The application of the preprocessing was effective since in the spectrum resulting from the analysis, only the band of interest for the detection of early failures is preserved.

Next, the calculation of bands or levels that make up the decomposition tree for multi-resolution analysis is performed based on the discrete wavelet transform, considering the sampling frequency that is given by the analog-to-digital converter module with 16-bit resolution, sampling frequency of 860 mps theoretical and programmable gain, there are 4 levels or branches left making resources efficient and demonstrating that a sampling high is not essential nor conditional, as has been done in most of similar works focused on this topic.

ISSN 2523-0344

Within which there is a greater interest in level four of detail coefficients with this, it is shown that a decomposition with a tree of many levels is not required to get favorable results.

To further improve the precision of the results and have a good performance with the detection index a post-processing is applied to all this, it is used an adequate index where we work with the signal and the coefficients of the results, optimizing the signal (Level cD4), limiting the extremes of this and reducing the signal the length of the kernel plus 14 points getting a smaller deviation of the tests is get regarding the analysis of the original signals and without the application SCPS-1SB, in charge of a specific work and improvement of the results in the detection of failures in the rotor of induction motors. This criterion is also very useful for adjusting and optimizing the comparison of the state of the motor through the graph resulting from cD4.

The proposed method reduces the uncertainty increasing accuracy to differentiate with clearly the state in which the motor is differed considerably increases the possibility of detecting in the conditions of failure with the motor no-load and permanent state, of rings and broken bars compared with conventional DWT analysis, and can more accuracy diagnose the different conditions, being to able can detect incipient failures with a light or low load, besides to eliminating the inconvenience of the analysis with load variation, either using Fourier Transform or conventional wavelet transform analysis. Here we focus on the range and we refine the characteristics of the signal that provides us with the identification and maximizing the difference that determines the state of the motor. With this work, certain points are corroborated, the fact that although it is possible to use the Fourier transform to detect faults, it is very difficult due to its proximity to the line frequency and special conditions are needed; on the other hand, it is shown that with the use and combination of several suitable tools for failure analysis can clearly detect these failures even with low load without need to implement tools that demand so many resources, obtaining the same and better results, finally it is shown that although high sampling gives good results for failure detection, it is not essential for the detection of the failures having a high resolution in sampling.

Referencias

[1] Marian N. (2005). *Fault Diagnostics of Electrical AC Machines*, Helsinki University of Technology, Laboratory of Electromechanics, Finland. URL: https://www.myecole.it/biblio/wp-content/uploads/2020/11/Fault-Diagnostics-of-Electrical-AC-Machines.pdf

[2] Castelli M. J., Fossati J.P., Andrade M. T. (2008). *Metodología de monitoreo, detection de fallos y diagnostico en motores asíncronos*, IEEE, 7º encuentro de Energía, Potencia, Instrumentación y Medidas, pp. 91-97.

[3] A. Sharma, S. Chatterji, L. Mathew, M. Junaid Khan, (2015). *A Review of Fault Diagnostic and Monitoring Schemes of Induction Motors*, International Journal for Research in Applied Science & Engineering Technology, Vol. 3, Issue 4, pp.1145-1152. *ISSN: 2321-9653*

[4] A. Sharma, L. Mathew; Sh. Chatterji, (2017). *Analysis of Broken Rotor bar Fault Diagnosis for Induction Motor*, International Conference on Innovations in Control, Communication and Information Systems. DOI: 10.1109/ICICCIS.2017.8660808

[5] M. Meira, C. Verucchi, A. Castellino, G. Bossio, (2021). *Detection of broken rotor bars and eccentricity during the starting transient of three-phase induction motors*, Workshop on Information Processing and Control. DOI: 10.1109/RPIC53795.2021.9648510

[6] D. Liu, H. Inoue, M. Kanemaru, (2022). *Robust Motor Current Signature Analysis (MCSA)-based Fault Detection under Varying Operating Conditions*, International Conference on Electrical Machines and Systems. DOI: 10.1109/ICEMS56177.2022.9983454

[7] J. Cusidó, L. Romeral, J. A. Ortega, J. A. Rosero, A. García Espinosa, (2008). *Fault Detection in Induction Machines Using Power Spectral Density in Wavelet Decomposition*, IEEE Transactions on industrial electronics, Vol. 55, No. 2, pp. 633-643. DOI: 10.1109/TIE.2007.911960

[8] A. Bouzida, O. Touhami, R. Ibtiouen, A. Belouchrani, M. Fadel, A. Rezzoug, (2011). *Fault Diagnosis in Industrial Induction Machines Through Discrete Wavelet Transform*, IEEE Transactions on industrial electronics, Vol. 58, No. 9, pp. 4385-4395. DOI: 10.1109/TIE.2010.2095391

[9] Y. Gritli, S. Bin Lee, F. Filippetti, L. Zarri, (2014). *Advanced Diagnosis of Outer Cage Damage in Double-Squirrel-Cage Induction Motors Under Time- Varying Conditions Based on Wavelet Analysis*, IEEE Transactions on industry applications, Vol. 50, No. 3, pp. 1791-1800. DOI: 10.1109/ECCE.2012.6342668

[10] S. Sbaa, N. Bessous, R. Pusca, R. Romary, (2020). *A comparative study dedicated to rotor failure detection in induction motors using MCSA, DWT, and EMD techniques*, International Conference on Electrical Motorering. DOI:10.1109/ICEE49691.2020.9249774

[11] Younas, M. B., Ullah, N., Taner Goktas, Arkan, M., Gurusamy, V. (2021). *The Performance Evaluation of Machine Learning based Techniques via Stator Current and Stray Flux for Broken Bar Fault in Induction Motors*. 2021 IEEE 13th International Symposium on Diagnostics for Electrical Machines, Power Electronics and Drives (SDEMPED), pp. 180-185. DOI:10.1109/SDEMPED51010.2021.9605516

[12] O. R. Agyare, A. B. Asiedu-Asante and A. R. Biney, (2019). *Fuzzy Logic Based Condition Monitoring of a 3-Phase Induction Motor*, 2019 IEEE AFRICON, pp. 1-8, DOI: 10.1109/AFRICON46755.2019.9133780.

[13] Guedidi, A., Laala, W., Guettaf A. (2020). *Diagnosis and Classification of broken bars fault using DWT and Artificial Neural Network without slip estimation*. 2020 XI International Conference on Electrical Power Drive Systems (ICEPDS).1(1). DOI: 10.1109/ICEPDS47235.2020.9249315

[14] chikkam, S., Singh, S. *Condition Monitoring and Fault Diagnosis of Induction Motor using DWT and ANN*. Arab J Sci Eng 48, 6237–6252 (2023). https://doi.org/10.1007/s13369-022-07294-3

[15] F. B. Costa, (2014). *Fault-Induced Transient Detection Based on Real-Time Analysis of the Wavelet Coefficient Energy*, IEEE Transactions on power delivery, Vol. 29, NO. 1, pp. 140-153. DOI: 10.1109/TPWRD.2013.2278272

[16] Sridhar. S, K. Uma Rao, S. Jade, (2015). *Detection of Broken Rotor Bar Fault in Induction Motor at Various Load Conditions Using Wavelet Transforms*, International Conference on Recent Developments in Control, Automation and Power Engineering. DOI: 10.1109/RDCAPE.2015.7281373

[17] N. Lahouasnia, M. Faouzi Rachedi, Th. Deghboudj, (2019). *Detection of Broken Rotor Bar Defect in Squirrel Cage Induction Machine*, International Conference on Advanced Electrical Motorering (ICAEE). DOI: 10.1109/ICAEE47123.2019.9015159

[18] M. Zawad Ali, L. Xiaodong, (2019). *Induction Motor Fault Diagnosis Using Discrete Wavelet Transform*, IEEE Conferencia Canadiense de Ingeniería Eléctrica e Informática (CCECE). DOI: 10.1109/CCECE.2019.8861923

[19] W. T. Thomson, Ian Culbert. (2017). *Current Signature Analysis for Condition Monitoring of Cage Induction Motors: Industrial Application and Case Histories*, John Wiley & Sons, Inc.

[20] K.R. Rao, D.N Kim, J.J Hwang, (2010). *Fast Fourier Transform: Algorithms and Applications*, Springer, ISBN: 978-1-4020-6628-3. DOI:10.1007/978-1-4020-6629-0

[21] A. Sapena Bañó, M. Pineda Sanchez, R. Puche Panadero, J. Martinez Roman, D. Matic, (2015). *Fault Diagnosis of Rotating Electrical Machines in Transient Regime Using a Single Stator Current's FFT*, IEEE Transactions on Instrumentation and Measurement, Vol. 64, No. 11, pp. 3137-3146. DOI: 10.1109/TIM.2015.2444240

[22] C. da Costa, M. Kashiwagi, M. H. Mathias, (2015). *Rotor failure detection of induction motors by wavelet transform and Fourier transform in non-stationary condition*, ELSEVIER Case Studies in Mechanical Systems and Signal Processing, pp. 15-26. https://doi.org/10.1016/j.csmssp.2015.05.00

[23] A C. Abhinandan, M. H. Sidram, (2017). *Fault Diagnosis of an Induction Motor through Motor Current Signature Analysis, FFT & DWT Analysis,* 4th IEEE International Conference on Motorering Technologies and Applied Sciences (ICETAS). DOI: 10.1109/ICETAS.2017.8277869

[24] S. Sbaa, N. Bessous, R. Pusca, R. Romary, (2020). *A comparative study dedicated to rotor failure detection in induction motors using MCSA, DWT, and EMD techniques*, International Conference on Electrical Motorering. DOI:10.1109/ICEE49691.2020.9249774

[25] Villalpando Hernández, Josué Uriel, Cabal Yepez, Eduardo, (2017). *Deteccion de barras rotas en motores de inducción utilizando la STFT*, Verano de la Investigación Científica, Vol. 3 No. 2. https://www.jovenesenlaciencia.ugto.mx/index.php/jovenesenlaciencia/article/view/1968/1464

[26] Rubi A. Ayon-Sicaeros, E. Cabal-Yepez, L. M. Ledesma-Carrillo, G. Hernandez-Gomez, (2019). *Broken-Rotor-Bar Detection Through STFT and Windowing Functions,* IEEE Sensors Applications Symposium (SAS) . DOI: 10.1109/SAS.2019.8706086

[27] Pineda caballero A. R. (1998). *Teoría de Wavelets, una alternative*, Thesis, Universidad Nacional Autonoma de Mexico, Acatlan, México.

[28] Quian Tao, Vai Mang, Xu yuesheng, (2007). *Wavelet Analysis and Applications*. Basilea Suiza: Birkhäuser Verlag. ISBN : 9783764377786

[29] J. Navarro Fuentes, D. Elizarraras Martinez, (2010). *Introduccion a la transformada Wavelet Continua*. Reverte, ISBN: 9786077815037

[30] D. Espinosa Pérez, J. Delgado, (2012). Tesis, *Wavelets y Superresolución*. http://mat.izt.uam.mx/mat/documentos/produccion_academica/toda_la_produccion/Tesis%20dirigidas-12-103.pdf

[31] C. Yun Guo, J. Ping Li, (2013). *Development and future of wavelet analysis*, 10th International Computer Conference on Wavelet Active Media Technology and Information Processing (ICCWAMTIP), pp. 335-338. DOI: 10.1109/ICCWAMTIP.2013.6716661

[32] L. Debnath, F. Ahmad Shah. (2015). *Wavelet Transforms and Their Applications*. Birkhäuser Boston DOI: https://doi.org/10.1007/978-0-8176-8418-1

[33] R. Narayan Dash, Ch. Panigrahi, B. Subudhi, S. Prasanna Saho, (2018). *Induction Motor Health Identification using Wavelet Transform Technique*, Technologies for Smart-City Energy Security and Power (ICSESP). DOI: 10.1109/ICSESP.2018.8376727

[34] O. Abdi Monfared, A. Doroudi, A. Darvishi, (2019). *Diagnosis of rotor broken bars faults in squirrel cage induction motor using continuous wavelet transform*, COMPEL The international journal for computation and mathematics in electrical and electronic motorering, Vol. 38, No. 1, pp. 167-182. https://doi.org/10.1108/COMPEL-11-2017-0487

[35] Sh. Md Kawsar Zaman, H. U May Marma, L. Xiaodong. (2019). *Broken Rotor Bar Fault Diagnosis for Induction Motors Using Power Spectral Density and Complex Continuous Wavelet Transform Methods*, IEEE Canadian Conference of Electrical and Computer Motorering (CCECE). DOI: 10.1109/CCECE.2019.8861517

[36] Su-Yun Huang, Zhidong Bai. (2003). *Wavelets, Advanced, Encyclopedia of Physical Science and Technology.Third Edition*, pp.753-771. https://doi.org/10.1016/B0-12-227410-5/00939-X

[37] B. Mahdi Ebrahimi, J. Faiz, S. Lotfi fard, P. Pillay, (2012). *Novel indices for broken rotor bars fault diagnosis in induction motors using wavelet transform*, Mechanical Systems and Signal Processing. Vol. 30, pp. 131-145. https://doi.org/10.1016/j.ymssp.2012.01.026

[38] P. Shi, Z. Chen, Y. Vagapov, (2013). *Wavelet Transform based Broken Rotor-bar Fault detection and Diagnosis Performance Evaluations*, International Journal of Computer Applications, Vol. 69, No.14, pp. 36-43. DOI: 10.5120/11913-8033

[39] H. Cherif, A. Menacer, B. Bessam, R. Kechida, (2015). *Stator Inter Turns Fault Detection Using Discrete Wavelet Transform*, IEEE 10th International Symposium on Diagnostics for Electrical Machines, Power Electronics and Drives (SDEMPED), pp. 138-142. DOI: 10.1109/DEMPED.2015.7303681

[40] Shruti Prins, Mini V.P., Mayadevi N., Harikumar R. (2018). *Detection of Broken Rotor Bars Using Multilevel Wavelet Decomposition*, Proceedings of the 2nd International Conference on Trends in Electronics and Informatics. DOI: 10.1109/ICOEI.2018.8553821

[41] Viraj U. Patel, (2019). *Condition Monitoring of Induction Motor for Broken Rotor Bar using Discrete Wavelet Transform & K-nearest Neighbor*, 3rd International Conference on Computing Methodologies and Communication (ICCMC). DOI: 10.1109/ICCMC.2019.8819637

[42] M. Singh, A. Gafoor Shaik, (2019). *Broken Rotor Bar Fault Diagnosis of a Three-phase Induction Motor using Discrete Wavelet Transform*, IEEE PES GTD Grand International Conference and Exposition Asia (GTD Asia), pp. 13-17. DOI: 10.1109/GTDAsia.2019.8715925

ISSN 2523-0344

Article **Journal Industrial Engineering**
June 2023, Vol.7 No.18 34-41

Preliminary Development of an upgrade of a chamber to measure the response of quartz crystal resonators

Desarrollo preliminar de la actualización de una cámara de medición de respuesta de sensores de gas de cristal de cuarzo

LOPEZ-RAMIREZ, Carlos Alberto†, MUÑOZ-MATA, José Lorenzo*, ROJAS-GARNICA Juan Carlos and CERVANTES-DE LA ROSA, Juan Pedro

Universidad Tecnológica de Puebla

ID 1st Author: *Carlos Alberto, López-Ramírez* / **ORC ID:** 0009-0003-0539-6243

ID 1st Co-author: *José Lorenzo, Muñoz-Mata* / **ORC ID:** 0000-0001-7813-5579, **CVU CONAHCYT ID:** 177117

ID 2nd Co-author: *Juan Carlos, Rojas-Garnica* / **ORC ID:** 0000-0002-2261-587X, **CVU CONAHCYT ID:** 66417

ID 3rd Co-author: *Juan Pedro, Cervantes-De La Rosa* / **ORC ID:** 0000-000I-6634-2018

DOI: 10.35429/JIE.2023.18.7.34.41 Received January 25, 2023; Accepted June 30, 2023

Abstract

Quartz crystal microbalance (QCM) sensors have been frequently used as weighing devices, since they have proven to be sensitive due to shifts in their resonant frequency due to increments in the mass attached to their surface. These, are normally used as sensor arrays for systems known as "Electronic Noses", to detect and analyze gases, fluids, medical and environmental applications, and biological compounds, among others. For the implementation of such systems, it is necessary to characterize the response of the sensors at different types of compounds, primarily in temperature-controlled environments, which implies the use of control systems with a high cost. This work presents the preliminary design of a static system to measure the response of quartz crystal gas sensors, as a lower cost proposal, using an open-loop controlled temperature environment, through an electronic communication system with the computer and a virtual instrumentation software to monitoring and manipulating the temperature. To observe the effectiveness of the system, real QCM gas sensors with a coat of sensing film of ethyl cellulose were used, applying concentrations of ethanol. In addition, temperatures of 25°C, 35°C and 45°C were adjusted, obtaining typical results of the response of this type of sensors.

QCM, Electronic Nose, Microcontrollers

Resumen

Los sensores de micro balanza de cristal de cuarzo (QCM) se han empleado frecuentemente como dispositivos de pesaje, puesto son altamente sensibles debido a corrimientos en su frecuencia de resonancia generados por incrementos en la masa adherida sobre su superficie. Estos, son usados como arreglos de sensores para sistemas conocidos como “Narices Electrónicas”, para detección y análisis de gases, fluidos, aplicaciones médicas, ambientales, compuestos biológicos, entre otros. Para implementar dichos sistemas es necesario caracterizar las respuestas de los sensores a diferentes compuestos, principalmente en ambientes de temperatura controlados, lo que implica el uso de sistemas de control con un alto costo. Este trabajo presenta el diseño preliminar de un sistema estático para medir la respuesta de sensores gas de cristal de cuarzo, como una propuesta a menor costo, usando ambiente de temperatura controlado en lazo abierto, a través de un sistema electrónico de comunicación con una computadora y software de instrumentación virtual para monitorear y manipular la temperatura. Para observar la efectividad del sistema se usaron sensores de gas QCM reales con película sensible de etíl celulosa aplicando concentraciones de etanol. Además, se ajustaron temperaturas de 25°C, 35°C y 45°C obteniendo resultados típicos de la respuesta de este tipo de sensores.

QCM, Nariz Electrónica, Microcontroladores

Citation: LOPEZ-RAMIREZ, Carlos Alberto, MUÑOZ-MATA, José Lorenzo, ROJAS-GARNICA Juan Carlos and CERVANTES-DE LA ROSA, Juan Pedro. Preliminary Development of an upgrade of a chamber to measure the response of quartz crystal resonators . Journal Industrial Engineering. 2023. 7-18: 34-41

* Author's Correspondence (e-mail: jose.munoz@utpuebla.edu.mx)
† Researcher contributing as first author.

Introduction

Electronic Noses had as a principal objective to replace to the expert panels in order to classified aromas for product testing, since such products were considered very expensive, difficult to transport and subjective, due to fatigue, mood, the weather and other external factors, could affect their evaluations. For this type of test support teams were used, such as gas chromatographs and mass spectrometers, in this case, to classifying and quantifying odors, with a high cost of production. Currently, electronic noses are used for the classification of aromas and odor detection that can be defined as: the emanation of emissions that matter radiates.

The electronic Nose applications have extended due to research in several fields. In agri-food industry had a great impact, helping to discriminate the degree of maturity of mangoes (Leburn, *et al*, 2008). In the monitoring of the environment, drinking water quality (Gardner *et a*l, 2000). In medicine, with the detection of volatile organic components detected through the breath as markers of lung cancer (Zhunan *et al*, 2003), and the detection of explosives in security systems (Edward J. Staples, 2007).

Quartz Crystal Microbalance Sensors (QCM) are very sensitive devices to small mass variations, due to the frequency shift in the resonant frequency of the quartz crystal. The Sauerbrey equation, describes the frequency shift on the sensor generated of the chance of the mass per unit on the electrode surface.

$$\Delta f = -2.3 \times 10^{-6} \cdot F^2 \frac{\Delta m}{A}, \qquad (1)$$

Δf is the frequency shift, $2.3x10^{-6}$ is a constant with the characteristics of the density and shear module, Δm is the absorbed mass, and F is the resonant frequency of the crystal (Sauerbrey 1959).

The operation of the crystals is effective and precise for the detection of various volatile organic compounds, which contains a quartz disc with two electrodes placed on both sides of the disc. Quartz is a material that is considered piezoelectric (Shaukat H, *et al*, 2023), since it can convert mechanical tension into electricity, and electricity into mechanical vibrations through the inverse effect (piezoelectric effect). In addition, they are highly sensitive to changes in temperature and humidity.

In a previous work it had been reported by (Muñoz. *et al* 2019). Design and implementation of a gas response measurement system, however, they used a different measurement chamber, which is limited by design in scope of the temperature ranges. Moreover, the transfer of information rate is performed at least every 500 ms, which slows the process of acquisition and response of the system.

In this work we present a preliminary development of a gas sensor response measurement system, in this particular case, only for quartz sensors, therefore, a measurement chamber was designed with the objective of optimize the temperature range. On the other hand, it is proposed to improve the acquisition time and to be able to optimize the signal processing firmware. Finally, additional actuators were added in order to increase the response time of the system (Gardner *et al*, 2000). For the experimental results, the temperature was controlled using a PID close loop regulator. In addition, 12 MHz QCM gas sensors were built with a sensitive film of ethyl cellulose applying ethanol samples, where it could be observed that the system yields typical responses corresponding to the QCM sensors.

Experimental setup

Figure 1 shows the block diagram used for the implementation of the proposed system.

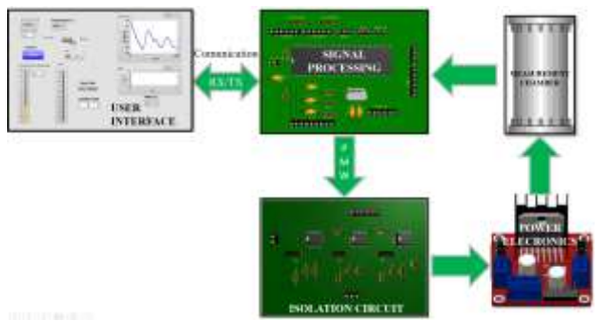


Figure 1 Block Diagram of the measurement system
Source: Self Made

As can be observed in Figure 1, the system consists of 5 stages: Control, Processing, Isolation, Power electronics and the camera.

ISSN 2523-0344

1.-Control System

LabVIEW software (Pineda-Olivares, 2018) was used to develop the user interface, through the RS-232 communications protocol using a data transfer rate of 9600 bauds per second and an acquisition and processing time of 100 ms, the information of the temperature sensor is received in order to monitoring and regulating the temperature of the interior of the measurement chamber. In this case, the digital sensor DS18B20 was used to measure the temperature with a resolution of 12 bits. Finally, the information is visualized numerically and graphically, as is shown in Figure 2.

Figure 2 User interface of the system developed using LabVIEW
Source: Self Made

2.-Signal Processing

The transformation of the information is performed through the asynchronous serial communication protocol using the PL2303 converter module, between the control stage and the processing stage, using the PIC16F877A microcontroller (García, E. (2009), at a frequency clock of 4 MHz. PWM signals are used to regulate the power applied to the actuators. Figure 3 shows the flowchart that corresponds to the firmware developed within the microcontroller.

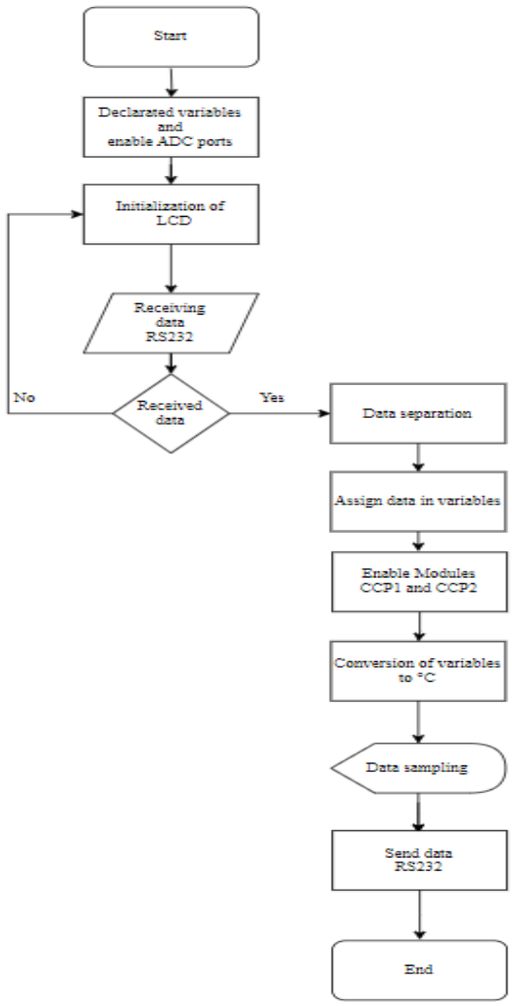


Figure 3 Flux diagram of the firmware development
Source: Self Made

3.-Isolation circuit

Figure 4 shows the circuit used to isolate the power electronics from the microcontroller using the optocouplers 4N25, in order to prevent a system failure in the microcontroller, additionally a transistor BC548 was used to maintain the current transfer of the signals.

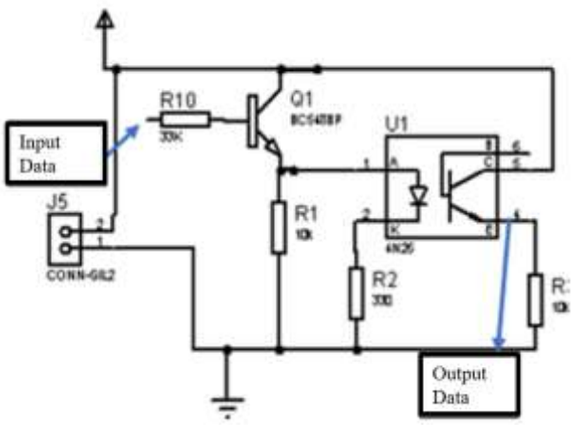


Figure 4 Isolation circuit
Source: Self Made

ISSN 2523-0344

4.-Power electronics

Once that the isolation circuit was performed the L298 module was used to control the power applied to the actuators, in this case, Peltier cells were utilized to control the interior of the measurement chamber.

5.-Measurement Chamber

A measurement chamber was designed to be capable to control the temperature of the QCM sensor. The CATIA 3D CAD (E. Torrecilla (2013), software was used to develop a model. Built it from steel in a nonagonal shape prism (Figure 5), with external dimensions of (ø:106 mm, H:200 mm) and internal dimensions of (ø:101.6 mm).

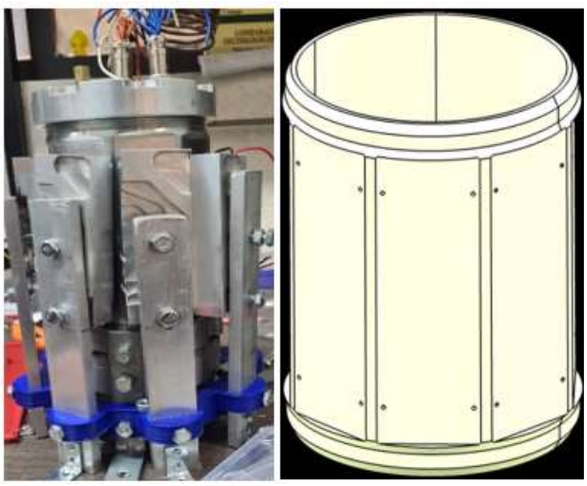


Figure 5 Measurement Chamber
Source: Self Made

A cover (ø:110mm, H:20mm) was designed with connectors for the temperature and QCM sensors that will be placed inside the camera. In addition, some arms are built, which are manufactured using steel in a CNC machine. Moreover, a support (Figure 6) is designed for the arms that hold the heatsinks and Peltier cells, the support was manufactured using ABS material to be printed on a 3D printer.

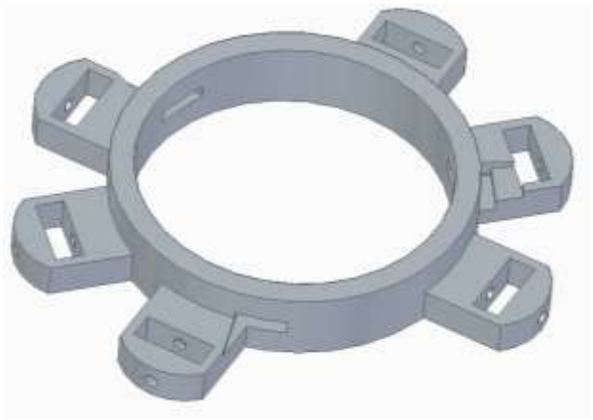


Figure 6 Arms support CAD
Source: Self Made

Experimental Results

In order to verify the correct operation of the system, QCM gas sensors with AT cut were built applying a sensing film of ethyl cellulose using the casting method. The crystal used for this experiment has a resonance frequency of approximately 12 MHz. Once the sensing film was applied, a frequency shift of $\Delta F = 4.39$ KHz was obtained, which implies a thickness of the sensing film of 0.11 μm. Figure 7 shows the impedance curve obtained from the sensor developed.

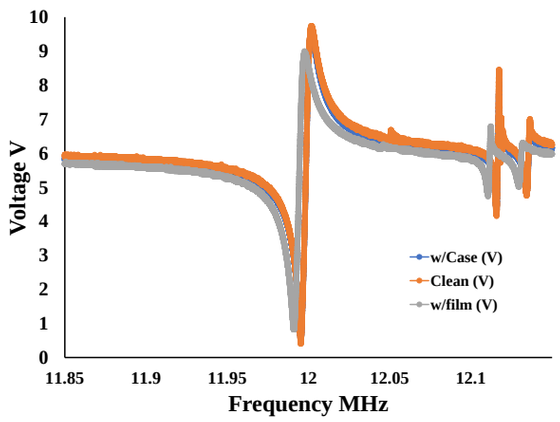


Figure 7 Impedance curves for a 12 MHz crystal with case, without case, and with sensing film.
Source: Self Made

Such plot shows the resonant frequency peak for each stage of the construction of the sensor, as can be observed, the sensor has proper performance.

Subsequently, once the sensor was ready and tested, the sensor response measurement stage was added, obtaining a complementary experimental arrangement, as shown in Figure 8.

ISSN 2523-0344

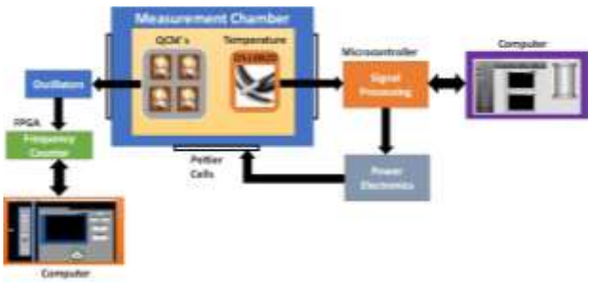


Figure 8 Complementary Experimental setup.
Source: Self Made

It can be observed an oscillator was added to excite the sensor using the piezoelectric principle to obtain the frequency response of the QCM sensor. A frequency counter is used to measure the sensor response (Muñoz Mata, *et al* 2012), with a resolution oh 1 Hz. Finally, the data are sent to the computer to visualize and store the sensor response information.

For the purpose of proving the effectiveness of the temperature regulation system developed, first, an open loop test was performed in order to obtain the resolution and range of the temperature of the implemented system. We could observe that the system heats at a rate of approximately 2°C/min over a range of 15°C to 50°C, and cools at a rate of approximately 0.8°C/min over a range of 50°C to 25°C, considering that the previous system achieved a heating time of approximately 0.9°C/min, with these results we achieve a significant improvement. Figure 9 shows the response ramp of one of the experimental tests performed.

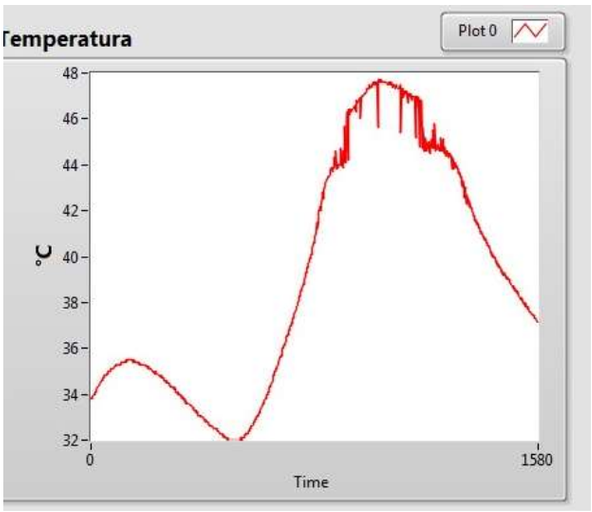


Figure 9 Response of the system in open loop
Source: Self Made

Figure 10 shows the temperature curve within the system using a PID controller (Hernández-Guzmán *et al* 2013), where the desired temperature i set at 30 °C. There is a closed-loop error range of approximately ± 1°C, with a proportional gain kp= 5 and an integral time constant Ti: 0.001. In this case, a derivative time constant was not used, since experiments are still being performed to optimize the controller.

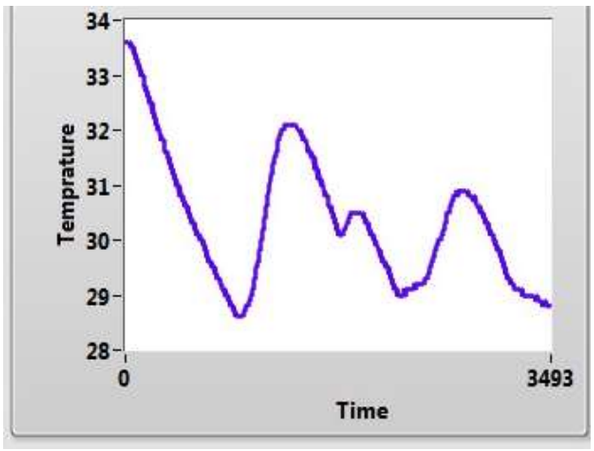


Figure 10 System response using a PID controller for a setpoint of 30 °C
Source: Self Made

Furthermore, the temperature was set at 25 °C, 35 °C and 45°C approximately. Experiments were performed, which consist in to measure the response of the gas sensor previously developed at three different temperatures.

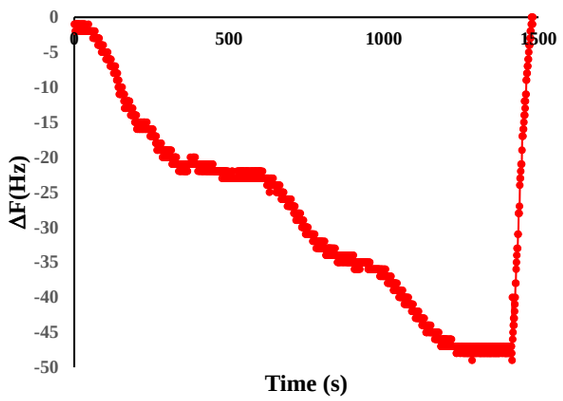


Figure 11 QCM gas sensor response at 25°C.
Source: Self Made

Once the temperature gradient is achieved at 25 °C, the frequency counter was started to measure the sensor response, applying 15500 pm of ethanol samples.

ISSN 2523-0344

In Figure 11 is shown the obtained response of the QCM sensor. As can be observed, the frequency shift for the first sample injection was of ΔF=22 Hz in 600 seconds approximately. When we applied the second sample a frequency shift of ΔF=37 Hz in 1150 seconds. For the third sample injection shows a ΔF=49 Hz in 1550 second approximately.
Figure 12 shows the obtained results of the sensor for a temperature inside the chamber of 35 °C, where significant differences can be appreciated.

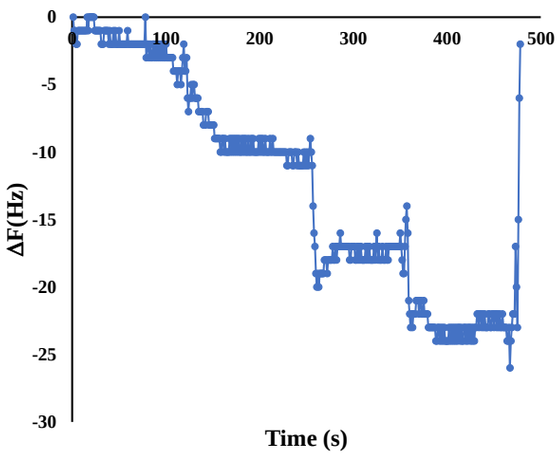


Figure 12 QCM Sensor response at 35 °C.
Source: Self Made

As the previous experiment, three ethanol samples were applied with the same ppm concentration. As can be observed, for the first sample injection, a frequency shift of ΔF=12 Hz in approximately 200 second was obtained. For the second sample was obtained a response of a frequency shift of ΔF=20 Hz in 390 second. When a third ethanol sample was injected, a shift of ΔF=25 Hz in a time of 550 seconds was obtained. As can be appreciated, when the temperature step is increased produces a shift in the base response of the sensor. Hence, if the temperature set increases the sensor base response decrements, due to the temperature effect in the measurement chamber, as well as the response time.

Finally, a third test was performed, the temperature was set at 45 °C, which experimental results can be observed in Figure 13. A frequency shift of ΔF=9 Hz was obtained after a first ethanol sample was applied. For the second sample a response of ΔF=17 Hz and ΔF=22 Hz for the third sample.

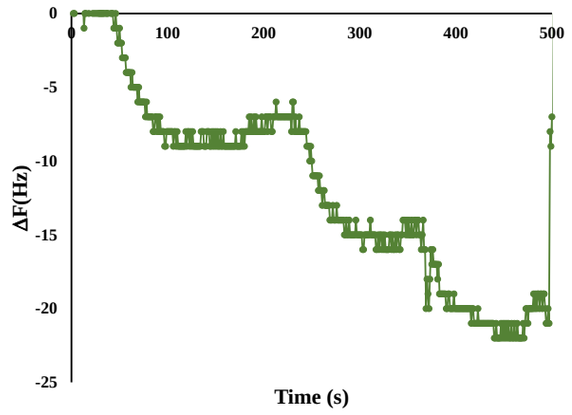


Figure 13 QCM sensor response at 45°C
Source: Self Made

.

In order to be able to appreciate the effects of the temperature of the measurement chamber for this type of QCM sensors, all the raw responses were plotted. As can be observed in Figure 14, there is a change in the frequency base-line of the sensor for each configured temperature step, which corroborates the fact that this type of QCM sensors is sensitive to changes of temperature.

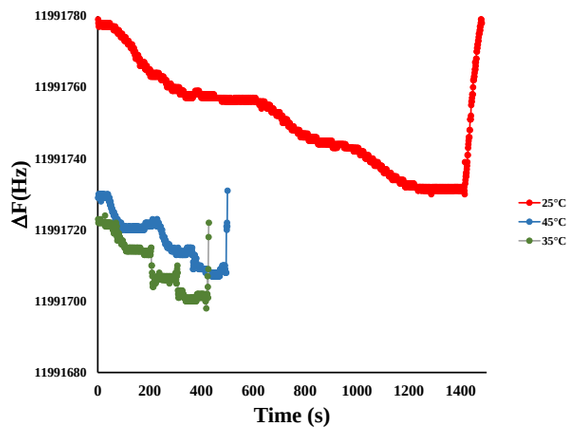


Figure 14 Raw response of the QCM sensors for different exposition of temperature
Source: Self Made

In addition, linear adjustments of the sensor response are obtained as a function of the applied concentration, as can be appreciate in Figure 15 for the response of the sensor exposed to a temperature of 25 °C, there is a correlation coefficient of R^2=0.9891.

ISSN 2523-0344

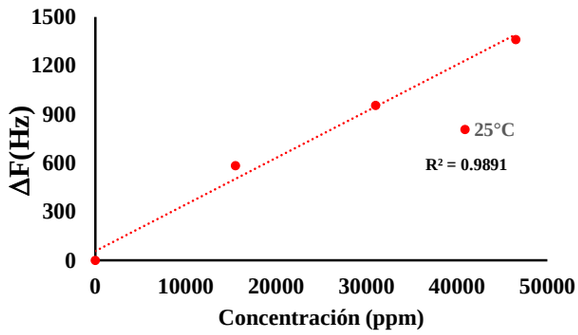


Figure 15 Linear adjustment of the frequency shift as a function of the concentration (correlation coefficient R^2) at 25 °C
Source: Self Made

For the case of the sensor response at a temperature of 35 °C we obtain a coefficient of R^2=0.9934, and for a applied temperature of 45 °C a correlation coefficient was achieved of R^2=0.9914 as observed in Figure 16.

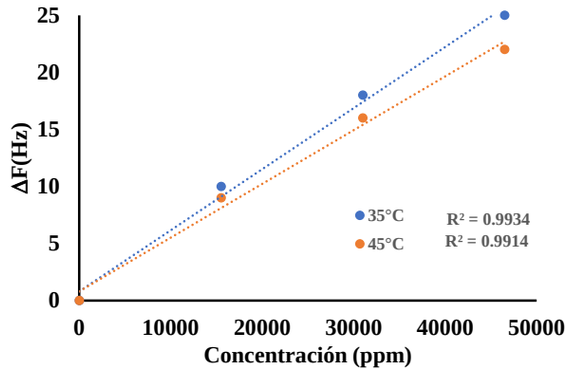


Figure 16 Linear adjustment of the frequency shift as a function of the concentration (correlation coefficient R^2) for 35 °C and 45 °C
Source: Self Made

As it could be observed, it had been obtained responses from real QCM sensors, such responses correspond to typical curves characteristics for sensors exposed at different temperatures, which indicates that the implemented system, at least preliminary, has a satisfactory performance.

Acknowledgments

To the Universidad Tecnológica de Puebla for the opportunity in the use of the facilities for the development of this project.

Conclusions

A preliminary system for the update of a quartz crystal gas sensor response measurement system has been developed, obtaining typical responses from QCM sensors exposed at different temperatures.

It is important to mention that the temperatures of the interior of the measurement chamber are reached in an approximate time of 10 minutes for 25°C, 16 minutes to reach 35°C and a time of 23 minutes for 50°C. In addition, after performing the experimental tests. we realized that the actuators (Peltiers) were not working properly, therefore, solving this issue, the system performance could be improved significantly.

The measurement chamber presents improvements with the reduction in thickness from 8 mm to 4.4 mm, thus, helping to distribute the temperature evenly inside the chamber. In addition, to being able to place more actuators in the system due to the design of the walls.

Future work

It is intended to improve the cooling speed, as well as the control algorithm of the control operation of the chamber. Sensors will be added to measure and control humidity inside the chamber. Moreover, temperature sensors will be placed on the base and the upper part of the chamber in order to collect more accurate information of the behavior of the temperature. In addition, it is planned to change the digital sensors to analog to improve accuracy.

References

Edward J. Staples (2007). Analysis of Odors from Explosives using an Electronic Nose. Recuperado de: Microsoft Word - Odors_of_Explosives.doc (techmondial.com). 12/06/23. http://www.estcal.com/TechPapers/Odors_of_Explosives.doc

E. Torrecilla (2013). El gran libro de Catia . (1a ed.). Barcelona, España: Alfaomega-Marcombo. ISBN: 978-970-15-1397-2. ISBN: 9788426720023.

ISSN 2523-0344

G. Sauerbrey *et al* (1959). Verwendung von Schwingquarzen zur W¨agung d¨unner Schichten und zur Mikrow¨agung Z, Zeitschrift für Physik 155, 206-222.

Hernandez, Guzmán *et al*, (2013). Control Automático, Teoría de diseño, construcción de prototipos, modelado, identificación y pruebas experimentales. (1ª Ed.). México ISBN: 978-607-414-362-1

J. L. Muñoz Mata, *et al* (2012). Development and implementation of system to measure the response of quartz crystal resonator-based gas sensor using a field programmable gate array, Measure Science and Technology, 23 (5),055104. DOI 10.1088/0957-0233/23/5/055104.

Leburn, *et al*, (2008). Discrimination of mango fruit maturity by volatiles using the electronic nose and gas chromatography. Recuperado de: Discrimination of mango fruit maturity by volatiles using the electronic nose and gas chromatography - ScienceDirect 12/06/23. https://doi.org/10.1016/j.postharvbio.2007.09.010

Gardner *et al*, (2000). An electronic nose system for monitoring the quality of potable water. Recuperado: PII: S0925-4005(00)00482-2 (warwick.ac.uk) 12/06/23. https://doi.org/10.1016/S0925-4005(00)00482-2

Muñoz. Et al (2019). Diseño e implementación de un sistema de medición de respuesta de gas. *Revista de aplicaciones de la ingeniería*, (6), 26-34. DOI:10.35429/JEA.2019.20.6.26.34

National Instruments Corporate Headquarters (2001). NI VISA User Manual. https://www.ni.com/pdf/manuals/370423a.pdf

Pineda-Olivares, A (2018). Instrumentación virtual. Fundamentos de programación gráfica con LabVIEW. (1ª. Ed.) México, Editorial Digital del Tecnológico de Monterrey. ISBN: 9786075011868, 6075011862

García, E. (2009). Compilador C CSS y Simulador PROTEUS para microcontroladores PIC. (2ª ed.). Barcelona, España: MARCOMBO. ISBN: 978-970-15-1397-2

Shaukat, H., Ali, A., Bibi, S., Altabey, WA, Noori, M. y Kouritem, SA (2023). Una revisión de los avances recientes en materiales piezoeléctricos, estructuras colectoras de energía y sus aplicaciones en química analítica. Ciencias Aplicadas, 13 (3), 1300. https://doi.org/10.3390/app13031300

Zhunan *et al*, (2003), Detection of Lung Cancer: Concomitant Volatile Organic Compounds and Metabolomic Profiling of Six Cancer Cell Lines of Different Histological Origins. Recuperado de: Detection of Lung Cancer: Concomitant Volatile Organic Compounds and Metabolomic Profiling of Six Cancer Cell Lines of Different Histological Origins (acs.org) 12/06/23. DOI: 10.1021/acsomega.7b02035 ACS Omega 2018, 3, 5131−514

ISSN 2523-0344

[Title in Times New Roman and Bold No. 14 in English and Spanish]

Surname (IN UPPERCASE), Name 1st Author†*, Surname (IN UPPERCASE), Name 1st Coauthor, Surname (IN UPPERCASE), Name 2nd Coauthor and Surname (IN UPPERCASE), Name 3rd Coauthor

Institutional Affiliation of Author including Dependency (No.10 Times New Roman and Italic)

International Identification of Science - Technology and Innovation

ID 1st Author: (ORC ID - Researcher ID Thomson, arXiv Author ID - PubMed Author ID - Open ID) and CVU 1st author: (Scholar-PNPC or SNI-CONAHCYT) (No.10 Times New Roman)

ID 1st Coauthor: (ORC ID - Researcher ID Thomson, arXiv Author ID - PubMed Author ID - Open ID) and CVU 1st coauthor: (Scholar or SNI) (No.10 Times New Roman)

ID 2nd Coauthor: (ORC ID - Researcher ID Thomson, arXiv Author ID - PubMed Author ID - Open ID) and CVU 2nd coauthor: (Scholar or SNI) (No.10 Times New Roman)

ID 3rd Coauthor: (ORC ID - Researcher ID Thomson, arXiv Author ID - PubMed Author ID - Open ID) and CVU 3rd coauthor: (Scholar or SNI) (No.10 Times New Roman)

(Report Submission Date: Month, Day, and Year); Accepted (Insert date of Acceptance: Use Only ECORFAN)

Abstract (In English, 150-200 words)

Objectives
Methodology
Contribution

Abstract (In Spanish, 150-200 words)

Objectives
Methodology
Contribution

Keywords (In English)

Indicate 3 keywords in Times New Roman and Bold No. 10

Keywords (In Spanish)

Indicate 3 keywords in Times New Roman and Bold No. 10

Citation: Surname (IN UPPERCASE), Name 1st Author, Surname (IN UPPERCASE), Name 1st Coauthor, Surname (IN UPPERCASE), Name 2nd Coauthor and Surname (IN UPPERCASE), Name 3rd Coauthor. Paper Title. Journal Industrial Engineering. Year 1-1: 1-11 [Times New Roman No.10]

* Correspondence to Author (example@example.org)
† Researcher contributing as first author.

Introduction

Text in Times New Roman No.12, single space.

General explanation of the subject and explain why it is important.

What is your added value with respect to other techniques?

Clearly focus each of its features

Clearly explain the problem to be solved and the central hypothesis.

Explanation of sections Article.

Development of headings and subheadings of the article with subsequent numbers

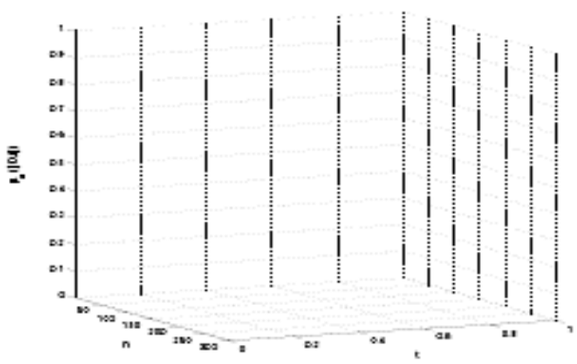
[Title No.12 in Times New Roman, single spaced and bold]

Products in development No.12 Times New Roman, single spaced.

Including graphs, figures and tables-Editable

In the article content any graphic, table and figure should be editable formats that can change size, type and number of letter, for the purposes of edition, these must be high quality, not pixelated and should be noticeable even reducing image scale.

[Indicating the title at the bottom with No.10 and Times New Roman Bold]



Graphic 1 Title and *Source (in italics)*

Should not be images-everything must be editable.

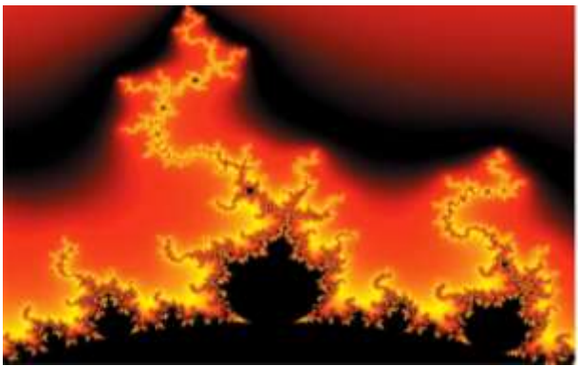


Figure 1 Title and *Source (in italics)*

Should not be images-everything must be editable.

Table 1 Title and *Source (in italics)*

Should not be images-everything must be editable.

Each article shall present separately in **3 folders**: a) Figures, b) Charts and c) Tables in .JPG format, indicating the number and sequential Bold Title.

For the use of equations, noted as follows:

$$Y_{ij} = \alpha + \sum_{h=1}^{r} \beta_h X_{hij} + u_j + e_{ij} \qquad (1)$$

Must be editable and number aligned on the right side.

Methodology

Develop give the meaning of the variables in linear writing and important is the comparison of the used criteria.

Results

The results shall be by section of the article.

Annexes

Tables and adequate sources

Thanks

Indicate if they were financed by any institution, University or company.

ISSN 2523-0344

Conclusions

Explain clearly the results and possibilities of improvement.

References

Use APA system. Should not be numbered, nor with bullets, however if necessary numbering will be because reference or mention is made somewhere in the Article.

Use Roman Alphabet, all references you have used must be in the Roman Alphabet, even if you have quoted an Article, book in any of the official languages of the United Nations (English, French, German, Chinese, Russian, Portuguese, Italian, Spanish, Arabic), you must write the reference in Roman script and not in any of the official languages.

Technical Specifications

Each article must submit your dates into a Word document (.docx):

Journal Name
Article title
Abstract
Keywords
Article sections, for example:

1. Introduction
2. Description of the method
3. Analysis from the regression demand curve
4. Results
5. Thanks
6. Conclusions
7. References

Author Name (s)
Email Correspondence to Author
References

Intellectual Property Requirements for editing:

- Authentic Signature in Color of Originality Format Author and Coauthors.

- Authentic Signature in Color of the Acceptance Format of Author and Coauthors.

- Authentic Signature in blue colour of the Conflict of Interest Format of Author and Co-authors.

ISSN 2523-0344

Reservation to Editorial Policy

Journal Industrial Engineering reserves the right to make editorial changes required to adapt the Articles to the Editorial Policy of the Research Journal. Once the Article is accepted in its final version, the Research Journal will send the author the proofs for review. ECORFAN® will only accept the correction of errata and errors or omissions arising from the editing process of the Research Journal, reserving in full the copyrights and content dissemination. No deletions, substitutions or additions that alter the formation of the Article will be accepted.

Code of Ethics - Good Practices and Declaration of Solution to Editorial Conflicts

Declaration of Originality and unpublished character of the Article, of Authors, on the obtaining of data and interpretation of results, Acknowledgments, Conflict of interests, Assignment of rights and Distribution

The ECORFAN-Mexico, S.C Management claims to Authors of Articles that its content must be original, unpublished and of Scientific, Technological and Innovation content to be submitted for evaluation.

The Authors signing the Article must be the same that have contributed to its conception, realization and development, as well as obtaining the data, interpreting the results, drafting and reviewing it. The Corresponding Author of the proposed Article will request the form that follows.

Article title:

– The sending of an Article to Journal Industrial Engineering emanates the commitment of the author not to submit it simultaneously to the consideration of other series publications for it must complement the Format of Originality for its Article, unless it is rejected by the Arbitration Committee, it may be withdrawn.

– None of the data presented in this article has been plagiarized or invented. The original data are clearly distinguished from those already published. And it is known of the test in PLAGSCAN if a level of plagiarism is detected Positive will not proceed to arbitrate.

– References are cited on which the information contained in the Article is based, as well as theories and data from other previously published Articles.

– The authors sign the Format of Authorization for their Article to be disseminated by means that ECORFAN-Mexico, S.C. In its Holding Republic of Peru considers pertinent for disclosure and diffusion of its Article its Rights of Work.

– Consent has been obtained from those who have contributed unpublished data obtained through verbal or written communication, and such communication and Authorship are adequately identified.

– The Author and Co-Authors who sign this work have participated in its planning, design and execution, as well as in the interpretation of the results. They also critically reviewed the paper, approved its final version and agreed with its publication.

– No signature responsible for the work has been omitted and the criteria of Scientific Authorization are satisfied.

– The results of this Article have been interpreted objectively. Any results contrary to the point of view of those who sign are exposed and discussed in the Article.

Copyright and Access

The publication of this Article supposes the transfer of the copyright to ECORFAN-Mexico, SC in its Holding Republic of Peru for its Journal Industrial Engineering, which reserves the right to distribute on the Web the published version of the Article and the making available of the Article in This format supposes for its Authors the fulfilment of what is established in the Law of Science and Technology of the United Mexican States, regarding the obligation to allow access to the results of Scientific Research.

Article Title:

Name and Surnames of the Contact Author and the Co-authors	Signature
1.	
2.	
3.	
4.	

Principles of Ethics and Declaration of Solution to Editorial Conflicts

Editor Responsibilities

The Publisher undertakes to guarantee the confidentiality of the evaluation process, it may not disclose to the Arbitrators the identity of the Authors, nor may it reveal the identity of the Arbitrators at any time.

The Editor assumes the responsibility to properly inform the Author of the stage of the editorial process in which the text is sent, as well as the resolutions of Double-Blind Review.

The Editor should evaluate manuscripts and their intellectual content without distinction of race, gender, sexual orientation, religious beliefs, ethnicity, nationality, or the political philosophy of the Authors.

The Editor and his editing team of ECORFAN® Holdings will not disclose any information about Articles submitted to anyone other than the corresponding Author.

The Editor should make fair and impartial decisions and ensure a fair Double-Blind Review.

Responsibilities of the Editorial Board

The description of the peer review processes is made known by the Editorial Board in order that the Authors know what the evaluation criteria are and will always be willing to justify any controversy in the evaluation process. In case of Plagiarism Detection to the Article the Committee notifies the Authors for Violation to the Right of Scientific, Technological and Innovation Authorization.

Responsibilities of the Arbitration Committee

The Arbitrators undertake to notify about any unethical conduct by the Authors and to indicate all the information that may be reason to reject the publication of the Articles. In addition, they must undertake to keep confidential information related to the Articles they evaluate.

Any manuscript received for your arbitration must be treated as confidential, should not be displayed or discussed with other experts, except with the permission of the Editor.

The Arbitrators must be conducted objectively, any personal criticism of the Author is inappropriate.

The Arbitrators must express their points of view with clarity and with valid arguments that contribute to the Scientific, Technological and Innovation of the Author.

The Arbitrators should not evaluate manuscripts in which they have conflicts of interest and have been notified to the Editor before submitting the Article for Double-Blind Review.

Responsibilities of the Authors

Authors must guarantee that their articles are the product of their original work and that the data has been obtained ethically.

Authors must ensure that they have not been previously published or that they are not considered in another serial publication.

Authors must strictly follow the rules for the publication of Defined Articles by the Editorial Board.

The authors have requested that the text in all its forms be an unethical editorial behaviour and is unacceptable, consequently, any manuscript that incurs in plagiarism is eliminated and not considered for publication.

Authors should cite publications that have been influential in the nature of the Article submitted to arbitration.

Information services

Indexation - Bases and Repositories

LATINDEX (Scientific Journals of Latin America, Spain and Portugal)
EBSCO (Research Database - EBSCO Industries)
RESEARCH GATE (Germany)
GOOGLE SCHOLAR (Citation indices-Google)
MENDELEY (Bibliographic References Manager)
HISPANA (Information and Bibliographic Orientation-Spain)

Publishing Services

Citation and Index Identification H
Management of Originality Format and Authorization
Testing Article with PLAGSCAN
Article Evaluation
Certificate of Double-Blind Review
Article Edition
Web layout
Indexing and Repository
ArticleTranslation
Article Publication
Certificate of Article
Service Billing

Editorial Policy and Management

1047 La Raza Avenue -Santa Ana, Cusco-Peru. Phones: +52 1 55 6159 2296, +52 1 55 1260 0355, +52 1 55 6034 9181; Email: contact@ecorfan.org www.ecorfan.org

Journal Industrial Engineering

2523 0344
ISSN 2523-0344