ISBN: 978-628-95207-4-3. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2023.1.1.804

Computational Numerical Control (CNC) Machines: A Systematic Review From 2015 To 2022

Espejo-Peña, Dennis Alberto[1], Felipe Celis, Jordan[2], De La Cruz Morales, Fredy Ronald[3], Acuña Rugel, Ricardo Eduardo Bruno[4] and Torres Lázaro, Renato Andrés[5]
[1,2,3,4,5]University National of Callao, Perú
despejop@unac.edu.pe, jfelipec@unac.edu.pe, frdelacruzm@unac.edu.pe, rebacunar@unac.edu.pe, ratorresl@unac.edu.pe

***Abstract*– The following systematic review tries to group together the most information about machines by computational numerical control (CNC) in order to find the benefits and limitations for the mechanical industry that will lead to optimize the approaches that have been addressed. The method that was carried out in the present work was the methodology based on the PRISMA strategy finding a total of 33 articles, which was divided into 5 approaches that are the following: production, manufacturing systematization, design and maintenance. The results show the impact of CNC machines on both benefits and limitations, in addition to the distribution of found items by years, countries and continental level.**

Keywords-- CNC Machines, Manufacturing, Performance, Benefits, Limitations

I. Introduction

In recent years, competition from the rapidly growing global industry has considerably raised standards in modern manufacturing. CNC machine tools convert raw metal workpieces into finished products, sequentially eliminating additional material by applying turning, drilling, and milling operations, driven by specifically encoded instructions. [1]

The emergence of the industry 4.0 trend has brought new challenges and opportunities to the heavy machinery industry. [2]

The industry 4.0 revolution pushed the integration of advanced control technologies by incorporating artificial intelligence and machine learning, which led to the development of intelligent CNC machining systems. These systems aim to increase production, ensure product quality, eliminate defects, and minimize operating costs [1]

Several powers and manufacturing regions in the world have presented relevant support plans for smart robot machining technology. For example, the European Union proposed the COMET project approach to improve the precision of the machining robot, Europe proposed the "HEPHESTOS" cooperation program to use a commercial robot to complete the processing of hard-to-machine materials. [3]

This review also shows work for different types of machining, detection, data acquisition, signal generation and processing. Therefore, tool status monitoring (TCM) of the cutters is very important to make timely decisions on changing the cutting part of the cutter or taking corrective measures to ensure that the parameters required for the finished part are met [4]

What are the benefits/limitations of a CNC machine?

The following work aims to investigate the impact that CNC machines have had on industries taking into account the benefits and limitations that have been faced.

Digital Object Identifier: (only for full papers, inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).
DO NOT REMOVE

II. Methodology

A systematic review of CNC machining was carried out using the prism methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses. We stated that our research question to guide the methodological process was as follows What are the benefits/limitations of a CNC machine?

A. Process of collection of information

The following descriptors were used to correlate the search with our theme: "CNC machining", "manufacturing", "performance", "obstacle", "benefits", "limitation" and "lathe". For a deeper search of the CNC machines, a search system was implemented with the following combinations of the already established terms: ["CNC MACHINING" AND "MANUFACTURING" AND ("PERFORMANCE" OR "OBSTACLE")], ["CNC MACHINING" AND "BENEFITS" AND "LIMITATION"] and ["CNC MACHINING" AND "MANUFACTURING" AND "BENEFITS" AND "LIMITATIONS" AND "LATHE"]. The following Science Direct, Scopus and EBSCOhost search engines were used as a database. The formulas for which the search was implemented are described below:

Scopus

"CNC machining" AND "manufacturing" AND ("performance" OR "obstacle")

EBSCO host

"CNC machining" AND "benefits" AND "limitation"

Science Direct

"CNC machining" AND "manufacturing" AND "benefits" AND "limitations" AND "lathe"

B. Inclusion and exclusion criteria

Original articles published in the database mentioned above, in English, were extracted because, in this language, it was possible to find a greater number of articles compared to the other languages and in addition the articles were taken into account between the years 2015 - 2022 it should also be noted that we consider that the articles are open access, considering that our approach and strategy of RS is associated with CNC machining of recent years.

As a criterion of exclusion, we took into account the similarity or duplicates of the articles found and studied by the redundancy of these. Then with the found articles we discarded those that did not agree with our research objective and/or differ from our research question, specifically taking the terms benefits and limitations.

The protocol of search and extraction of information was applied by 4 reviewers independently, later the selection of the articles was done jointly being these very objectives; of which the differences were resolved by mutual agreement.

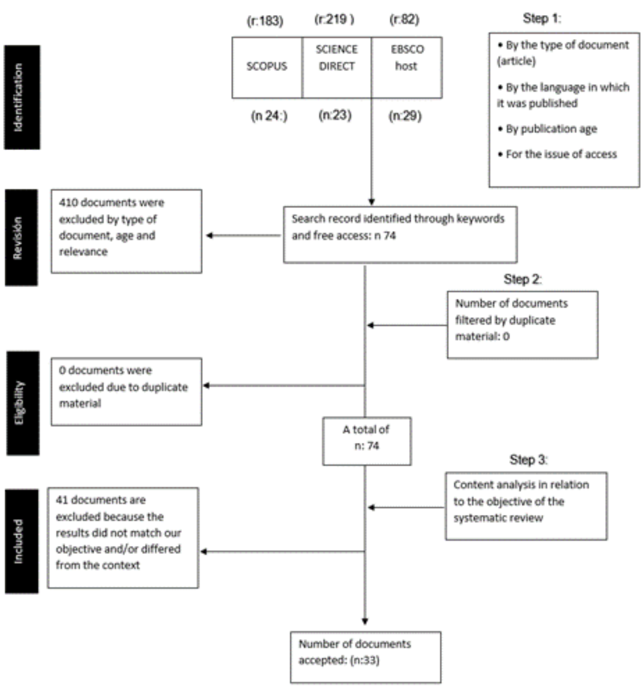

Fig. 1 Flowchart.

III. Results

Of the 33 articles selected for which we have distributed them by years where in the first two years of the decade studied (2015-2016), only 6 papers were found. The publications identified were concentrated in the last half of the chosen decade. Between 2017 and 2019, 11 articles were published, exceeding the total number of publications of the previous two years. In the last three years (2020 to 2022) 16 articles were published, about 49% of all those collected and included in this research.

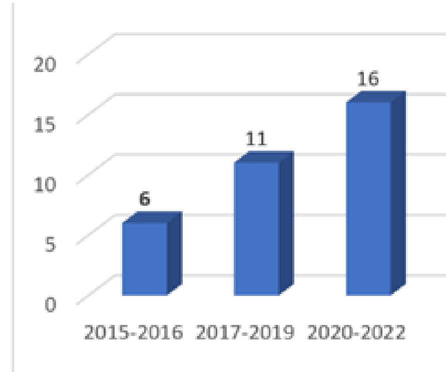

Fig. 2 Number of items per year

In the bar graph we can see that the number of articles is a subject of interest as it increases over the years. The results show that the year in which the most articles were found was between 2020 and 2022, compared to the first 2 years in which the number of articles was lower.

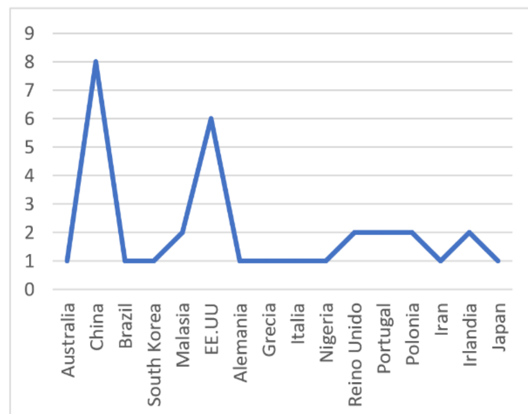

Fig. 3 Number of items per country

From this graph it is shown that the number of items based on CNC machining is most studied in the country of China followed by the United States.

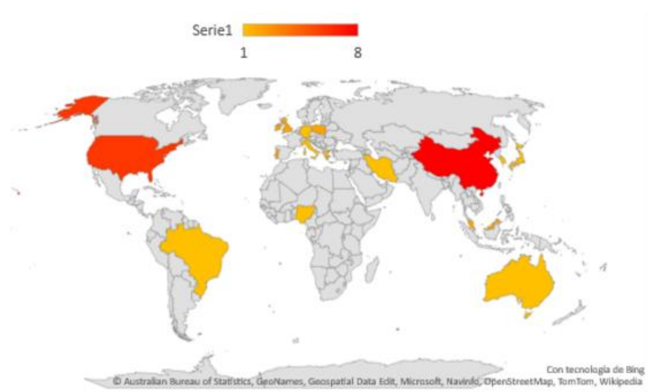

Fig. 4 Number of items per country

At the continental level, Africa and Oceania has at least one published article, and the results also show the origin of the articles worldwide, with the majority of articles extracted from China, unlike 9 countries where only one item was found.

TABLE I
ARTICLES INCLUDED IN THE REVIEW ACCORDING TO THE KEYWORDS USED.

Article	Source	Country
[1]	The International Journal of Advanced Manufacturing Technology	Australia
[2]	Advances in Materials Science and Engineering	China
[3]	Production	Brasil
[4]	High Temperature Materials and Processes	South Korean
[5]	International Journal of Automotive and Mechanical Engineering	Malasia
[6]	Materials	China
[7]	International Journal of Advanced Manufacturing Technology	China
[8]	International Journal of Advanced Manufacturing Technology	Alemania
[9]	Journal of Engineering Science and Technology	China
[10]	*International Journal of Innovative Technology and Exploring Engineering*	Malasia
[11]	*International Journal of Production Research*	Grecia
[12]	*Journal of Cleaner Production*	China
[13]	*International Journal of Production Research*	EE. UU
[14]	Journal of Manufacturing Science and Engineering, Transactions of the ASME	EEE.UU
[15]	*IEEE Access*	China
[16]	*Engineering Science and Technology, an International Journal*	Nigeria
[17]	*Applied Soft Computing*	Reino Unido
[18]	*Procedia Manufacturing*	Portugal
[19]	*Procedia CIRP*	China
[20]	*Procedía Manufacturing*	Polonia
[21]	*Energy Reports*	Irán
[22]	*Alexandria Engineering Journal*	Irlanda
[23]	*Procedia CIRP*	EE. UU
[24]	*Procedia CIRP*	Irlanda
[25]	*Applied Mathematical Modelling*	Reino Unido
[26]	*International Sampe Technical Conference*	EE. UU
[27]	*Robotics & Computer-Integrated Manufacturing*	Italia
[28]	*Sensors*	Portugal
[29]	*Tribology & Lubrication Technology*	EE. UU
[30]	*Symmetry*	China
[31]	*Materials*	Polonia
[32]	*Applied Sciences*	Japón
[33]	*Rapid Prototyping Journal*	EE. UU

TABLE II.
BRIEF SUMMARY OF THE ARTICLES INCLUDED IN THE REVIEW.

Article	BRIEF SUMMARY
[1]	The objective of this work is to investigate the co-efficiency of 3D printed metal parts compared to ined parts, to determine the technical, economic and ntal indicators.
[2]	RBF neural networks were used to solve the production process. Problems RBF neural network technology to control CNC electronics
[3]	Research contributes to the creation and development of a new way of presenting information that systematizes data collection and creates semantic relationships that can be used to analyze the productivity of healthcare manufacturing using semantic rules and machines of reasoning.
[4]	The hybrid production system can be widely used for large-scale production of molds of various shapes as a cost-effective alternative to conventional production methods.
[5]	This article focused on manufacturing the basic structure of a balanced and unbalanced wave guide coupler 1x2 power generator.
[6]	This article proposes an approach for simultaneous cutting of the tooth surface and tooth base using a single step cutting knife.
[7]	The integrated system gives users the ability to estimate production capacity before actual operation and reduces the test time to develop cutting parameters.
[8]	Suggest using voxel-based concepts introduced in the computer graphics industry to speed up material removal simulations.
[9]	The design of the structure in the 5-axis gantry for CNC machining centers seeks better production by integrating CAD/CAE technologies as an alternative for improvement in the experimentation and simulation of working conditions.
[10]	CNC machining is a manufacturing process in which tools and machine work by means of a computer program, designed to move parts and tools by means of numerical data.
[11]	Since overall optimization is largely based on problem formulation, emphasis has been placed on defining optimization criteria as crucial elements to represent performance.
[12]	In order to optimize manufacturing with energy efficiency is that it resorted to an immune system

	enabled by Big Data, programming is a critical stage to minimize the life cycle cost in manufacturing.
[13]	The virtual factory concept is presented as the vehicle for modeling and simulation of manufacturing where a path is proposed for its implementation that is based on technology developments and standards for the analysis of manufacturing data.
[14]	Subtractive 3D printing (i.e., 3D machining) is represented as an integration between 3D printing modeling and computer numerical control (CNC) machining through GPU-simulated software through route planning
[15]	The complexity of the manufacturing industry requires computer numerical control (CNC) machining by developing intelligent planning based on manufacturing and efficiency
[16]	Propose a novel clamping strategy for workpieces with the help of intelligent clamping force control (SCFC) for the purpose of adjusting the feed motion of the jaw and reducing the damage caused by the jaw on the workpiece depending on the material.
[17]	This paper first reviews different methods for designing thermal error models, to design two thermal prediction models: ANFIS by dividing the data space into rectangular subspaces (ANFIS-Grid model) and ANFIS using the fuzzy c-means clustering method (model ANFIS-FCM. A study of a small CNC milling machine is used to provide training data for the proposed models and then to provide independent test data sets
[18]	This article deals with the implementation of a strategic plan for maintenance. The methodology chosen was Total Productive Maintenance (TPM) and the cells chosen for its implementation were CNC lathes and CNC machining centers. TPM. focuses on eliminating efficiency losses
[19]	This paper discusses the different manufacturing systems SMEs can adopt, including flexible manufacturing systems (FMS), lean manufacturing (LM) and reconfigurable manufacturing systems (RMS)
[20]	The document notes and discusses a risk and reliability analysis. In addition, teaching methodologies are indicated in the area of CTP, in order to formulate the appropriate approach of engineers within the phase of implementation of the CPs.
[21]	This article points out and discusses a risk and reliability analysis. In addition, three MG planning objectives are considered, including ensuring sustainable and safe operation of CNC machines as sensitive loads, minimizing MG construction and operation costs
[22]	In this article he talks about an orthogonal matrix L 18 2 *3 4 to select the optimal cutting parameters to manufacture a template using a CNC milling machine. The Taguchi method was used to obtain a combination of cutting parameters, while RSM was used as an optimization technique to obtain the optimal Ra value by forming a second-order regression model.
[23]	This document examines machine tool life cycles and recent advances in extending their life cycles. A life cycle is defined as one that begins from design, progresses through the manufacturing and use stages, and is completed at the end of the service life.
[24]	The combination of sensors and acquisition which proves the validity of these techniques in a live production environment. Sensor data acquisition and optical tool wear measurements are controlled by a computer automatically without the intervention of the machine tool operator
[25]	This article introduces a new intelligent compensation system to reduce thermal errors in machine tools using data from a thermal imager
[26]	This article is about the machinability of recycled carbon fiber printed in 3D from a prototype part, the researchers were able to determine a spindle speed and feed speed suitable for fiber, which produced a visually uniform machined surface quality suitable for composite molds and production components.
[27]	This article discusses the filament extrusion-based manufacturing process that integrates the computer-aided design system, computer numerical control and the extrusion process to manufacture physical parts without geometric constraints
[28]	This article aims to make a review of the different techniques and force measurement devices developed for machining processes, allowing a quick perception of the advantages and limitations of each technique, through the research carried out, These forces can be obtained mainly by two methods, either by using a predictive method or by calculating/measuring these cutting forces.
[29]	This article talks about the benefits of additive manufacturing which are waste reduction, greater production efficiency, greater freedom and design flexibility, low cost for small parts batches, ability to produce complex parts and small to high volume.
[30]	This article talks about the attention mechanism that is introduced to perceive in a self-adaptive way the weights of the network associated with the classification results of the state of wear and distribute the weights in a reasonable way.
[31]	This article talks about the combination of different

	treatments of various technologies produces synergy, that is, benefits greater than the optimization of each individual process separately. It was used in the study which was a combination of milling and finishing with plastic burnishing using a ceramic ball. It is particularly useful for forms and values of residual stress, which are difficult to measure.
[32]	This study aims to automate the selection of machine tools by evaluating and comparing machining processes for the machining of specific parts. A fundamental method for the analysis of machining processes is proposed by introducing the functional description of the machine tools from the previous study.
[33]	This study speaking article is to compare the environmental impacts of two additive manufacturing machines with a traditional computer numerical control (CNC) milling machine to determine which method is the most sustainable.

TABLE III.
IMPACT OF THE MACHINES BY CNC

Article	Impact	
	Benefit	Limitation
[1]	eco-efficient mainly due to lower standardised environmental impacts (54,6 %)	
[2]	the roundness error and roughness error of the machined part were reduced by 70 % and 50 % respectively.	Failure to determine initial weights of parameters based on errors in the processing process, limiting their application in processing control.
[3]	Reduction of human errors in data collection, errors in production control and data loss.	
[4]	Increased equipment performance in terms of production when operating conditions are optimized.	
[5]	High production thanks to a mould design that can be manufactured several times.	
[6]	Improved efficiency, especially for cutting non-ferrous metals, also optimization of tool path to ensure mesh performance, further confirmed by FEM	has critical inferior aspects compared to traditional SBG manufacturing forms: efficiency is low and machining accuracy may not guarantee qualified meshing performance.
[7]	I provide users with a way to evaluate manufacturing performance before performing actual operations and reduce test time for developing cutting parameters.	the big challenge now is to further improve the surface quality metric inspection technology.
[8]	further improves the computational performance of volumetric algorithms based on high spatial precision voxels. They now allow very fast and precise simulation and analysis of volume removal of machining processes.	
[9]	Improved overall performance and design efficiency. the machining center.	Used beams can affect the performance of the whole machine.
[10]	Improved static and dynamic beam performance improving the overall performance of CNC machining centers.	The beams used can affect the performance of the whole machine, they are main components of the five-axis gantry machining center.
[11]	improved surface roughness through the application of the automated refrigerant supply system.	
[12]	Energy savings of around 30% and improved productivity of more than 50% have been achieved by adopting I2 S in factories.	The N/S mechanism is rigid, which hinders the robustness and precision of the immune process.
[13]	reduction of the effort and associated cost required to deploy virtual factories in successive factories and allow a large number of manufacturers to benefit.	
[14]	High performance and cloud computing through subtractive 3D printing parallel computing	

	application in the future.	
[15]	CNC processing performance indices become transparently tangible and shareable among stakeholders in the manufacturing value chain.	
[16]	Energy Saving.	
[17]	ANFIS Machine accuracy at 80 ANFIC-FCM produced better result with 94% improvement in error.	
[18]	Reduced costs increase and increase the useful life of equipment.	Worker resistance, time to adapt in the new routine. Implement and maintain the new routine.
[19]	Increased efficiency and reliability.	Finance and used equipment.
[20]	Decreased risk of failure, Decreased costs.	Small number of machine parts and lack of knowledge and experience.
[21]	FER better penetration in the range of 20% to 30%, better costs.	
[22]	Superior roughness was obtained with 21,934%.	
[23]	Longer lifespan and also higher production.	
[24]	Longer lifetime of used equipment.	
[25]	Better performance and no increase in overhead calculations.	
[26]	It produced a visually smooth machined surface quality suitable for composite molds and production components.	.
[27]	A spindle speed and feed rate suitable for fiber, which produced a visually uniform machined surface quality suitable for composite molds and production components.	The results are only applied when the machining surface remains flat and a reamer is the tool of choice.
[28]	Greater manufacture of physical parts without geometric limitations.	
[29]	Rapid perception of the advantages and limitations of each technique, through the bibliographic research carried out, using recently published works.	While there are recent studies showing prediction methods that provide high confidence rates, there are others that still require adequate validation.
[30]	Additive manufacturing is waste reduction, higher production efficiency, greater freedom and design flexibility, low cost for small parts batches.	3D printing and additive manufacturing are often used interchangeably, but additive manufacturing is broader and covers more commercial and industrial applications).
[31]	High precision and an acceleration sensor to collect in real time the vibration signals generated during tooling.	
[32]	Combining different methods is better than optimizing each individual process separately.	It is particularly useful for forms and values of residual stress, which are difficult to measure.
[33]	Increased production by automating a selection of machine tools.	

This graph shows the results of the categorization of the topics to be discussed.

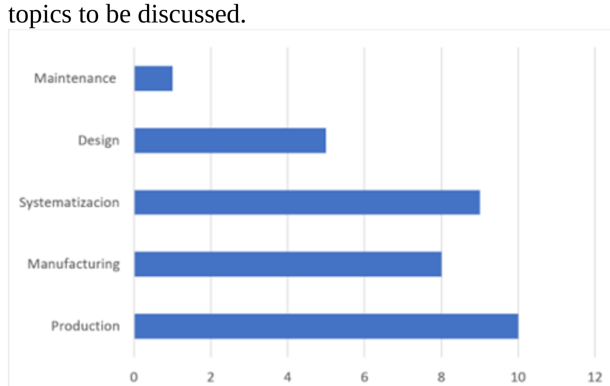

Fig. 5 Approaches to the articles.

IV. Discussions

Considering the results found, it could be said that the implementation of CNC machines in the industries has been beneficial, however, some limitations have also been found; it can also be understood that the technology within CNC machining is constantly updated and innovated not only in the field of manufacturing but also in the programming that this requires, the structure involved in these important machines in their design for good work, the optimization and efficiency required in processes and other aspects involving good use of technology.

The reported findings show that for the production approach has been found a number of 10 articles unlike maintenance where we only find an article that focuses on that item.

4.1. Production

In [1] the results show that the impeller is eco-efficient due to the lower standard environmental impacts (54.6%). In the same way [4] and [9] they mainly talk about the performance of those machines which were instrumental in obtaining higher production; however, in [9] we find a limitation which is that the beams implemented can affect this performance of the whole machine. On the other hand, the article [11] mentions that by obtaining a better roughness on the surface it was essential to obtain a greater production that eventually led to a better performance. In the case of article [21] we found that a greater penetration of the cutting tool in the ranges of 20% to 30%, plus a greater economic benefit. In [23] a longer service life of the machine was obtained and a greater production thus generating greater income. As regards Article [32] we find that the use of a combination of different technological treatments leads to better benefits. As far as the article [33] is concerned, there is clear evidence that, by automating the selection of machine tools, it leads to an improvement in production.

4.2. Systematization

Article [3] shows a clear reduction in human errors in order to obtain greater accuracy in data collection and security in storage. Articles [7], [8], [14], [15] and [25] show that an improvement in the performance of the machine was achieved; however, as regards article [7] it was evidenced a challenge which would be to improve even more the technology of metric inspection which proposes a sanitary manufacture using semantic rules and machines of friction. On the other hand, the article [10] obtained surface roughness by applying the automatic coolant supply system, but a limitation found was that lubrication also helps to prevent chips from sticking to the tool, so, if this happened, the chips would hinder the subsequent cutting. For Articles [12] and [16] energy savings were achieved, but in [12] some 30% were achieved and productivity improved by more than 50%, but the mechanism implemented is rigid, which hinders the robustness and precision of the immune process and finally in the article [24] a greater lifetime was obtained to the used equipment which reduces the expenses in machineries.

4.3. Manufacture

The experimental results of [2] show that, after integrating RBFNN control technology into the nanomaterials CNC machining process, the roundness error and roughness error of the machined part were reduced by 70 % and 50 %, respectively; however, it also has some deficiencies, such as the impossibility of determining the initial weights of the parameters according to errors in the processing process, which limits its application in the control of the processing. The article [5] refers to the fact that a less complex technique was obtained in which a mould was manufactured in order to obtain a higher productivity. In the cases of Articles [6], [19] and [30] a better efficiency was obtained; however, for Article [6] it still has critical lower aspects compared to traditional forms of SBG manufacture: the efficiency is low and the precision of the machining may not guarantee the performance of qualified meshing moreover in article [9] the limitation found is that the finances of the equipment are expensive and with respect to article [30] Additive manufacturing terms are often used interchangeably, but additive manufacturing is broader and covers more commercial and industrial applications. The article [13] emphasizes reducing the effort and associated cost required to deploy virtual factories in successive factories which will allow a large number of manufacturers to benefit. With regard to Article [20] it deals with the reduction of the risk of failure and also costs; however, a small number of spare parts for machines and lack of knowledge and experience are found and finally in Article [31] obtained high precision and an acceleration sensor to collect in real time the vibration signals generated during tool machining.

4.4. Design

Article [22] obtained a roughness greater than 21.934% using the Taguchi method to obtain a combination of cutting parameters; however. the results are only applied when the machining surface remains flat, and a reamer is the tool of choice. For article [27] where it refers to the surface quality which is suitable for moulds and production components. On the other hand, the article [28] speaks that the implemented design is ideal for the manufacture of physical parts without geometric limitations. And finally, the article [29] shows a rapid perception of the advantages and limitations of each technique; however, recent studies that show prediction methods that provide high confidence rates, there are others that still require adequate validation.

4.5. Maintenance

In [18] there was evidence of a reduction in costs and at the same time an increase in the useful life of the used equipment in which a strategic plan was used which the chosen methodology was Total Productive Maintenance

(TPM), as well as focusing on eliminating losses of efficiencies; However, some limitations are the worker resistance and the time it takes to adapt in the new routine which are points against which it must be reinforced.

V. Conclusions

Analysis of the literature shows that computational numerical control (CNC) machines have greater influence in countries where they have a great impact on the manufacturing industry not only but also on the design, the structure, the software and that in one way or another form part of the technological development; however the same cannot be concluded of the areas where the technology is scarce and only the theory is focused to arrive at the approximate result of a good management of the CNC machines.

The use of CNC machines had a positive impact on the industries, incidentally, not only in production, but also in systematization, manufacturing, design and maintenance.

In the production approach it is essential that CNC machines meet good performance efficiency, for example, better surface roughness of machined parts as a result. In order to get a high production. This also involves finding the limitations of the tools and machines, an example of the installation of beams in too much causing low performance.

The lifespan of machines and tools are limitations that must be properly managed for their longer duration, thus generating greater production and greater income. For cutting tools is also applied, operating them professionally. A study reveals that higher penetration of these in ranges of 20% to 30% are adequate.

The many technologies applied, such as automation to machine tools, are also used to improve production and make better profits.

In addition, the production approach takes into account reducing the environmental impacts caused by the machining operations of CNC machines. And for this it is essential that they have integrated eco-efficient system.

Among all the benefits found, most point to the performance obtained by the machines to achieve greater production, thus generating greater revenue and, consequently, reducing costs.

The CNC systematization is carried out through the numerical control of the machines, where algorithms and instructions are introduced, previously programmed, which executes the machine tool during machining, thus giving way to the control of all its movements in an automated way without hardly human intervention. In the articles focused on this heading, the clear reduction of human error stands out, thus greater accuracy of the data, however, the great challenge of systematization is the optimization of the metric inspection technology in general. It should be noted that systematization helps a lot in improving productivity to its counterpart we will indicate that accuracy is diminished by the mechanism that is rigid.

In terms of manufacturing because here together with the hand to design a less complex technique was manufactured where a mold was manufactured which would help to obtain more parts in a short time which having an increase in productivity, However, one limitation was that equipment finances are expensive, in addition to a small number of spare parts for machines and also lack of knowledge and experience to operate such machines.

Although it appears that there is an average interest in design, the researchers studied focus on the surface as an indispensable parameter for the ideal manufacture and production but not on the technical limitations that certain machines can provide with confidence rates of little validation.

Good maintenance management has a great impact on the success of an organization, understanding it can allow greater efficiency in aspects related to maintenance by providing cost reduction, longer life of a piece of equipment and its availability, as well as having an efficient computer system where it can be foreseen, created and managed correctly.

References

[1] M. Ntemi, S. Paraschos, A. Karakostas, I. Gialampoukidis, S. Vrochidis y l. Kompatsiaris, «Infrastructure monitoring and quality diagnosis in CNC machinig: A review,» CIRP Journal of manufacturing Science and Technology , pp. 631-649, 2022.

[2] M. Michalec, P. Svoboda, I. Krupka y M. Hartl, «A review of the design and optimization of large - scale hydrostatic bearing systems,» Engineering Science and Technology, an International Journal, pp. 936-958, 2021.

[3] Z. ZHU, X. TANG, c. CHEN, F. PENG, R. YAN, L. ZHOU, Z. LI y J. WU, «High precision and efficiency robotic milling of complex parts: Challenges, approaches and trends,» Chinese Journal of Aeronautics, pp. 22-46, 2022.

[4] D. Y. Pimenov, M. K. Gupta, L. RR da Silva , M. Kiran, N. Khanna y G. M.Krolczyk, «Application of measurement systems in tool condition monitoring of Milling: A review of measurement science approach,» Measurement, 2022.

[5] H. Jayawardane, . I. J. Davies, . J. Gamage, M. John y W. K. Biswas, «Investigating the 'techno-eco-efficiency' performance of pump impellers: metal 3D printing vs. CNC machining,» International Journal of Advanced Manufacturing Technology, 2022.

[6] H. Wang y F. Meng, «Control Method of Nanomaterial Numerical Control Electronic Processing Based on RBF Neural Network,» Advances in Materials Science and Engineering, 2022.

[7] S. T. Helena, V. R. S. Camargo, T. V. B. Amaral, A. L. Szejka, A. F. C. S. De Moura Leite y M. B. Canciglieri, «Interoperable data extraction and information enrichment system to support smart manufacturing: An experimental application on CNC machining lines of a healthcare product,» Production, 2022.

[8] J. Lee, J. Song, . Y. C. Lee y J. T. Kim, «Development of a huge hybrid 3D-printer based on fused deposition modeling (FDM) incorporated with computer numerical control (CNC) machining for industrial applications,» High Temperature Materials and Processes, 2022.

[9] Ghazali M.S.M., Romlay F.R.M. y Ehsan A.A., «Manufacturing of Polymer-based 1x2 Y-branch Symmetric and Asymmetric Waveguide

Coupler through Moulding Technique,» International Journal of Automotive and Mechanical Engineering, 2021.
[10]H. Xu, Y. Zhou, Y. He y J. Tang, «An efficient approach to the five-axis flank milling of non-ferrous spiral bevel gears,» Materials, 2021.
[11]C.-F. J. Kuo y W.-H. Weng, «An integrated curvature surface inspection and prediction system for 5-axis synchronization machining,» International Journal of Advanced Manufacturing Technology, 2021.
[12]F. Schnös, D. Hartmann, B. Obst y G. Glashagen, «GPU accelerated voxel-based machining simulation,» International Journal of Advanced Manufacturing Technology, 2021.
[13]X. Li, Y. Huang y Z. Zhou, «Structural design and optimization in the beam of a five-axis gantry machining center,» Journal of Engineering Science and Technology Review, 2020.
[14]W. N. ‘. Wan Md Hatta, F. A. Jafar, F. M. Nor y A. Z. M. Noor, «Machinibility performance of CNC turning based on automated coolant supply system,» International Journal of Innovative Technology and Exploring Engineering, 2019.
[15]N. A. Fountas, N. M. Vaxevanidis, C. I. Stergiou y R. Benhadj-Djilali, «Globally optimal tool paths for sculptured surfaces with emphasis to machining error and cutting posture smoothness,» International Journal of Production Research, 2019.
[16]Wang S., Liang Y.C., Li W.D. y Cai X.T., «Big Data enabled Intelligent Immune System for energy efficient manufacturing management,» Journal of Cleaner Production, 2018.
[17]S. Jain, G. Shao y S.-J. Shin, «Manufacturing data analytics using a virtual factory representation,» International Journal of Production Research, 2017.
[18]Z. Wu, T. M. Tucker, C. Nath, T. R. Kurfess y R. W. Vuduc, «Step ring-based three-dimensional path planning via graphics processing unit simulation for subtractive three-dimensional printing,» Journal of Manufacturing Science and Engineering, Transactions of the ASME, 2017.
[19]C.-S. Chen y Y. T. A. Sun, «Intelligent Computer-aided Process Planning of Multi-axis CNC Tapping Machine,» IEEE Access, 2017.
[20]B. I. Oladapo, Balogun V.A., Oyegoke S., Adeoye A.O.M., Ijagbemi C.O., Afolabi S.O., Daniyan I.A., Akinola S.O., Simeon A.P. y Uchegbu I.D., «Experimental analytical design of CNC machine tool SCFC based on electro-pneumatic system simulation,» Engineering Science and Technology, an International Journal, 2016.
[21]Ali M.Abdulshahed, Andrew P.Longstaff, SimonFletcher y AlanMyers, «Thermal error modelling of machine tools based on ANFIS with fuzzy c-means clustering using a thermal imaging camera,» Applied Mathematical Modelling, 2015.
[22]JonathanDowney, SebastianBombiński, MirosławNejman y KrzysztofJemielniak, «Automatic Multiple Sensor Data Acquisition System in a Real-time Production Environment,» Procedia CIRP, 2015.
[23]G. Robert X y PengWang, «Through Life Analysis for Machine Tools: From Design to Remanufacture,» Procedia CIRP, 2017.
[24]P.W.Anggoro, Y.Purharyono, Abet A.Anthony, M.Tauviqirrahman, A.P.Bayuseno y Jamari, «Optimisation of cutting parameters of new material orthotic insole using a Taguchi and response surface methodology approach,» Alexandria Engineering Journal, 2022.
[25]M.Naderi, S.Bahramara, Y.Khayat y H.Bevrani, «Optimal planning in a developing industrial microgrid with sensitive loads,» Energy Reports, 2017.
[26]RomanWdowik, R.M. ChandimaRatnayake, MarekMagdziak y ArturBełzo, «Technological process planning focused on complex manufacturing processes of the digital era,» Procedia Manufacturing, 2020.
[27]Jian Wang, Yuyang Du, Zhanxi Wang, Fei Yu y Chen Zheng, «Survey of manufacturing systems in SMEs: A focus on cell management,» Procedia CIRP, 2022.
[28]G.Pinto, F.J.G.Silva, A.Baptista, Nuno O.Fernandes, R.Casais y C.Carvalho, «TPM implementation and maintenance strategic plan – a case study,» Procedia Manufacturing, 2020.
[29]Ali M.Abdulshahed, Andrew P.Longstaff y SimonFletcher, «The application of ANFIS prediction models for thermal error compensation on CNC machine tools,» Applied Soft Computing, 2015.
[30]Peng Hao Wang, S. Ahsan y R. Sterkenburg, «INVESTIGATING THE MACHINABILITY OF 3D PRINTED RECYCLED CARBON FIBER,» International Sampe Technical Conference, 2019.
[31]A. Boschetto, L. Bottini y F. Veniali, «Finishing of Fused Deposition Modeling parts by CNC machining,» Robotics & Computer-Integrated Manufacturing, 2016.
[32]V. F. C. Sousa, F. J. G. Silva, J. S. Fecheira, H. M. Lopes, R. P. Martinho, R. B. Casais y L. P. Ferreira, «Cutting Forces Assessment in CNC Machining Processes: A Critical Review.,» Sensors, 2020.
[33]D. Smolenski, «Additive manufacturing: A threat to machining? Complementing and competing with computer numerical control machining.,» Tribology & Lubrication Technology, 2021.
[34]Q. Chen, Q. Xie, Q. Yuan, H. Huang y Y. Li, «Research on a Real-Time Monitoring Method for the Wear State of a Tool Based on a Convolutional Bidirectional LSTM Model.,» Symmetry, 2019.
[35]D. Grochała, S. Berczyński y Z. Grządziel, «Analysis of Surface Geometry Changes after Hybrid Milling and Burnishing by Ceramic Ball.,» Materials, 2019.
[36]W. Komatsu y K. Nakamoto, «Machining process analysis of multi-tasking machine tools based on form-shaping motions.,» Precision Engineering, 2022.
[37]J. Faludi, C. Bayley, S. Bhogal y M. Iribarne, «Comparing environmental impacts of additive manufacturing vs traditional machining via life-cycle assessment.,» Rapid Prototyping Journal, 2015.