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Zero Defect Manufacturing Using Digital Numerical Control

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Abstract
This paper proposes the application of the digital numerical control (DNC) technique to connect the smart meter to the inspection system and evaluate the total harmonic distortion (THD) value of power supply voltage in IEEE 519 standard by measuring the system. Experimental design by the Taguchi method is proposed to evaluate the compatibility factors to choose Urethane material as an alternative to SS400 material for roller fabrication at the machining center. Computer vision uses artificial intelligence (AI) technique to identify object iron color in distinguishing black for urethane material and white for SS400 material, color recognition results are evaluated by measuring system, system measurement is locked when the object of identification is white material SS400. Computer vision using AI technology is also used to recognize facial objects and control the layout of machining staff positions according to their respective skills. The results obtained after the study are that the surface scratches in the machining center are reduced from 100% to zero defects and the surface polishing process is eliminated, shortening production lead time, and reducing 2 employees. The total operating cost of the processing line decreased by 5785 USD per year. Minitab 18.0 software uses statistical model analysis, experimental design, and Taguchi technical analysis to evaluate the process and experimentally convert materials for roller production. MATLAB 2022a runs a computer vision model using artificial intelligence (AI) to recognize color objects to classify Urethane and SS400 materials and recognize the faces of people who control employee layout positions according to their respective skills.

Keywords
Digital Numerical Control, Taguchi, ANOVA, Lean Six Sigma.

Introduction

The precision of the mechanical parts processing industry is associated with other industries such as assembling automatic, semi-automatic machines, tools, or many other applications. Most of the moving and bearing structures of the product use mechanical components. The more precise the structure, the more precise the quality requirements of mechanical components are. Quality assurance of mechanical components is a necessary condition to improve competitiveness. Along with the rise of other economies such as Taiwan, Korea, China, India, etc., Japanese companies need to improve product quality even more. After processing, product design such as brightness, and surface roughness (Ra) are always essential factors to attract customers at first sight. SQCT (Safety-Quality-Cost-Time) is the 4 factors to assess competitiveness outside the business market. Quality management models from Japanese companies constantly contain certain principles that other foreign companies always want to learn more and more (Burduk et al., 2021).

According to the definition of a quality management standard, product quality should be within a set of points of conformity with the requirements of customers and other stakeholders. Good quality is not only good product quality, but the most advanced is the "eye of the customer" about which is most suitable for the purpose and processing conditions. In the quality hierarchy (Fig. 1), the quality management policy is visualized with related indicators, the balanced scorecard, which represents content such as quality management and business performance. Besides, the product quality improvement activities according to the QC (Quality Control) model failed to meet the requirements of product quality, service quality to im-

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prove customer satisfaction, and all criteria, Operation in a hierarchical model is accomplished through the Total Quality Management (TQM) system.

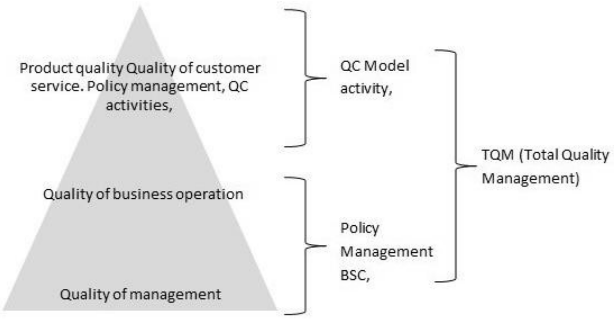


Fig. 1. Results of the comparative analysis of IT systems

One of the activities of the TQM system is to integrate the SDCA (Standardize-Do-Check-Action) model to detect the problem and the PDCA (Plan-Do-Check-Action) cycle to solve the problem to create a new model. (Fig. 2), detect the problem and propose the solution to the problem.

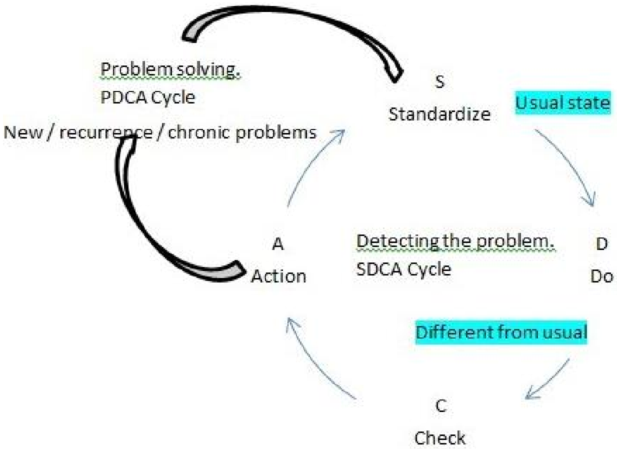


Fig. 2. Combine SDCA cycle

Use industrial tools to analyze, identify problems and implement to determine what problem needs to be eliminated, perform verification to eliminate problems not necessary to solve, and improve results in future (Fig. 3) process flowchart analysis and problem identification. The QC model (7 steps) is incorporated into the problem point analysis, analytical activity, identifying problems, and solving problems with integrated 7 steps, called QC activity, which is commonly applied in many companies around the world. However, the QC model (7 steps) has not yet implemented the content, depending on the location of the analytical research activities, it is necessary to explain

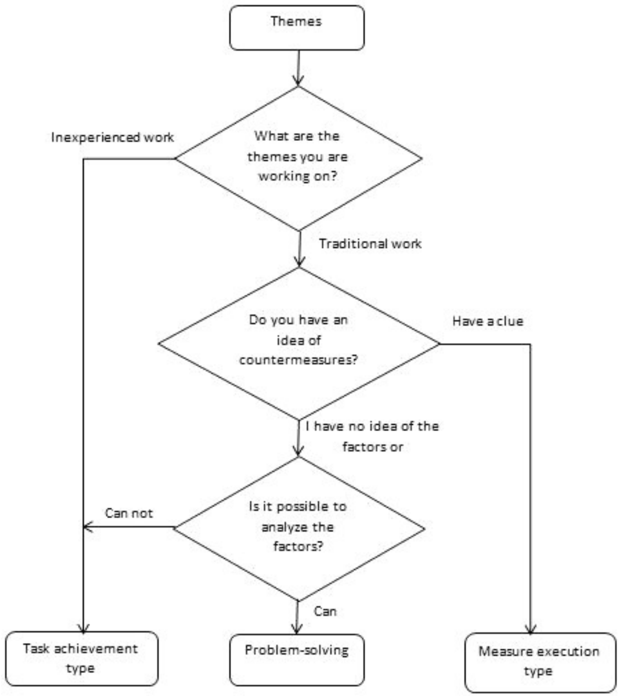


Fig. 3. Quality hierarchy

the organization and workplace from the beginning to study the research object. The second point, no action has been taken to reflect on the outstanding points after completing the improvement activities, and at the same time, we need to clarify the unfinished problem points or inadequate content and evaluate feedback about the good and bad sides of the content from users. The third is that there is no content showing that in the future, the contents and plans will be implemented. The new QC model adds 3 steps to the existing QC model to complete the continuous improvement model (Table 1).

Roller fixed the surface of the product to be machined with the hole size at the machining center, causing scratches on the surface of the product, the surface roughness is greater than RA0.4Max (see Fig. 4 and Fig. 5), additional lapping and 2 employees working in 2 shifts must be added. different to lapping 100% of the product surface, wasting lapping, increasing labor costs and increasing machining lead time. The surface of the vibrating roller will scratch the surface of the product, the electric cylinder is unstable, causing the roller to vibrate (see Fig. 7), the power supply for the electric cylinder is 230 voltage 3-phase. Harmonic components generated in the power supply greater than IEEE 519 (greater than 5%) affect the quality of the power supply. Whether the electric cylinder control circuit runs stable or not depends on the power quality, control the total harmonic dis-

Table 1
The new QC model

Step	Contents	Explain
0	Introduction	Add more
1	Theme selection	QC (7 steps)
2	Understanding the current situation and setting goals	
3	Creating an activity plan	
4	Factor analysis	
5	Planning and implementation of measures	
6	Confirmation of effect	
7	Standardization and establishment of management	
8	Reflection / remaining problems	Add more
9	Plan for the future	Add more

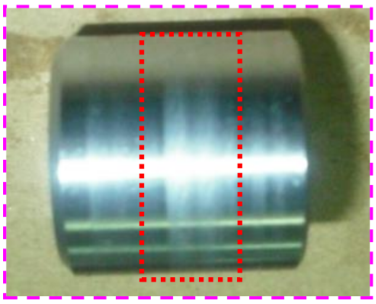
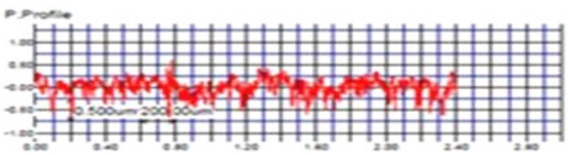


Fig. 4. Scratches surface roughness not reached



1	M.PartName		S.lenght	0.800mm	Rp (µm)	0.54
	Coumment		Levelling	Straight (all)	RSm (mm)	0.132
	Cutoff	Lc0.8mm	JIS'01/ISO'		JIS'94	
	Standards	JIS'94	Ra (µm)	0.5	Ra (µm)	0.5
	V.Mag	x2,000	Rz (µm)	2.48	Ry (µm)	2.48
	Filter	Gauss	Rt (µm)	2.8	Rz (µm)	2.08
	M.Speed	0.2mm/s	Rp (µm)	1.13	Sm (mm)	0.132
	E.Lenght	2.400mm	Rv (µm)	1.35	S (MM)*	0.026

Fig. 5. Result of Scratches surface roughness

tortion (THD) less than 5%, the power quality will be more stable, and the roller will operate more stable, the content will be more stable. THD control to improve power quality, improve roller stability is an urgent problem point.

The hardness of the roller material (58 HRC to 62 HRC) and the product hardness (58 HRC to 62 HRC) are also urgent issues that need to be researched and verified whether they can cause scratches on the surface of the product or not by using this method for experimental study. Machine condition, machining process parameters, and product dimension quality need to be saved online as big data by digital numerical control technique. Measured data, recognized whether it passes or not by the system, over and above eliminating dependence on employee skills. Towards perfecting the production process according to industrial 4.0 technology

In this study, it is suggested to use noise filter TAC-4-30A for 230 3-phase power and measure power quality with the smart meter to collect power quality data online into an inspection system. Experimental analysis by the Taguchi method evaluates the machining field parameters to select the best material for the roller. Value stream mapping measures valuable and non-valued and valuable activities, then reconstruct the future value stream mapping (Humiras & Mukhlisin, 2018). Computer vision technology uses artificial intelligence (AI) technology to recognize color objects, control employees to use accurately types of roller, and control employees layout according to the correlation skills on each stage.

The study yielded some main results as follows: (1) Surface scratches were eliminated 100% at the machining center. (2) Eliminating the lapping stage and 2 employees operating the 2-shift lapping stage. (3) Reducing product processing costs, improving quality, and reducing the lead time of full-line machining. (4) Raising employees' awareness of applying new techniques (digital numerical control and computer vision using artificial intelligence) into the production process.

The next content of the research paper is organized as follows: evaluating related studies as a premise for research. Then, identifying research subjects in the case study for improvement section. The theoretical basis of research materials and methods is the following content. The results are presented in the research results, discussion, conclusions section, and future research directions are the final contents of the research. In this article, a list of references is shown at the end of the research paper.

Literature review

Today, with the industry 4.0 manufacturing environment, companies make data on production and business outsourcing activities, data on outsourcing and business systems as well as life cycle information. Products are also detailed. In the process, the adaptation, as well as the impact of the product on the surrounding living environment and living resources is the top concern, the green Six Sigma tool contributes to increasing the influence of the product in the living environment. Rohin Titmarsh et al. (2020) proposed applying the Six Sigma cycle to the industrial 4.0 manufacturing environment based on information and communication technology to the Lean Six Sigma relationship in the DMAIC cycle (Srisuk & Tippayawong, 2020) to improve the machining process (Titmarsh et al., 2020). In the product processing process, fluctuation in the output of the process is the top concern, enterprises apply Six Sigma to the machining cycle to minimize the fluctuations in the output, which is realized through the processing cycle. DMAIC process and at each cycle is used quantitative and qualitative statistical tools to determine the variable factors and evaluate the process according to the 6-Sigma standard. However, in small and medium-sized companies, there is a lack of resources for Six Sigma awareness, so it is very difficult to implement Six Sigma. The quality management philosophy called Six Sigma has been strongly developed over the past 20 years. However, with the unstructured complexity of large volumes of data as well as the complexity of manufacturing processes and supply chains, Six Sigma can not solve the problem. To support the Six Sigma tool in solving the above problems, the process mining tool is very suitable, the Six Sigma tool through surveying Six Sigma professionals, a technical experiment, and a multi-case study in a company in search of big data processing capabilities in manufacturing plants (Kregel el al., 2021). Improvement activities to reduce loss costs, reduce operating costs, improve productivity and increase customer satisfaction by applying Six Sigma tools, which are adopted and bring significant benefits to many companies (De Mast et al., 2012), applying Lean Six Sigma tools to implement quality improvement activities in the product processing process to improve product quality, eliminate waste and improve productivity, as well as improve productivity such as enhancing competitive advantages for manufacturing enterprises by applying the DMAIC cycle (D – Define, M – Measure, A – Analyze, I – Improve, C – Control) to existing stages (Kosieradzka & Ciehcańska, 2018) and processes practices need to make improvements and cycle DMADV (D – Define, M – Measure, A – Analyze, D – Design, V – Verify) into the product design process (Pugna el al., 2016). In the product processing process, the fluctuation in the output of the process is the top concern, enterprises apply Six Sigma to the machining cycle to minimize the fluctuations in the output, which is realized through the processing cycle. DMAIC process and at each cycle is used quantitative and qualitative statistical tools to determine the variable factors and evaluate the process according to the 6 Sigma standard (Minh et al., 2019). However, in small and medium-sized companies, the lack of resources with Six Sigma awareness makes it very difficult to implement Six Sigma implementations (Deeb et al, 2018). In an organization, improving the process from product development to product outsourcing is a mandatory requirement for the organization to grow and compete with rival companies. Continuous improvement is a vital element of an organization, especially a component manufacturing company (Boon Sin et al., 2015). Improvement activities to reduce loss costs and operating costs, improve productivity and increase customer satisfaction by applying Six Sigma tools, which are adopted by many companies and bring significant benefits (Costa et al., 2017). The relationship between quality management and process performance is a concern that needs to be analyzed. Conducted a survey of numerous companies with many types of processing, and many different types of products on the relationship between quality control activities and efficiency of the machining process (Costa et al., 2019). The results obtained 144 survey results and empirical analysis shows a necessary relationship between quality control activities, process machining efficiency, and continuous improvement activities in the production process (Nguyen et al., 2018). Improve the production process to perform tasks such as improving the machining process, machining jigs, the layout of the machining area to add added value to the production line, and conduct interviews with 24 stories Participating in the outsourcing organization include mechanical technicians, electrical technicians, and area leaders, interviewing contents such as the reduction of waste, the training of the workforce, and the translation of corporate goals into intangible goals for the plant, the results show that the key points in the implementation of continuous improvement are the satisfaction level of employees in the organization who are afraid to change the implementation process, and do not want to change what is being done. Select an appropriate interpreter to solve the above difficulties (Castro & de Camargo Junior, 2020), evaluate the current state of documents related to the record of improvement activities at the manufacturing company, and determine the content that is not achieved or hinders continuous improvement activities through a survey containing content such as the problem, group the variables affecting the problem, develop the research model and theoretical frameworks, and test the variables, word analysis survey results were received and classified into 6 contents affecting continuous improvement activities (Soliman, 2017), status assessment activities based on field documents related to improvement activities continuity and performance investigation based on the results of the evaluation documents, the results show that there are still some limitations in continuous improvement activities such as the actual unclear process of continuous improvement, the activities encouraging the implementation of inadequate improvement, despite existing difficulties, and implementation perfecting the continuous improvement cycle (Lizarelli & de Toledo, 2016). As with any product processing process, when a product is generated, it reduces the stability of the process and increases the risk that the goods will not reach the customer and upset the customer, which means the profit. The company's profit will be reduced (Barot et al., 2020). The operation of the product processing process depends a lot on human skills and manipulations, during the operation of the machining parameters are not if the order is wrong, the risk of product waste (Ranade et al., 2021), using a combination of tools such as the critical to quality (CTQ), the voice of the customer (VOC) and Pareto Chart along with costs Six Sigma's DMAIC process in control of product processing and removal of non-value-added factors along with improving product quality (Srinivasan el al., 2014), implemented expert opinion survey on the link between six sigma implementation and operational performance is closely linked, six sigma project if the operation is successful, the productivity of the company will also increase accordingly (Boon Sin el al., 2015).

Previous studies only stopped surveying experts regarding the implementation of improvements. Improvement methods did not collect user and expert opinions and maintained the results after implementation. Improvements, as well as no experiments to evaluate and select the optimal parameters for the improved design before implementing it into practice. The powerful Taguchi experiment is the optimal and simple experimental method, which is easy to implement at the production site (Sharma et al., 2017), and performs data collection for experimental research to be carried out. Through the field operator, the analysis results are analyzed by the field technician on Minitab 18.0 software with the participation of the field operator. The strength of the operator's direct participation continuing into the experimental research process is the main topic of this study that has not been covered by previous studies. Continuous improvement is carried out according to the PDCA cycle, but there is no evaluation item, user survey, and the results of the improvement activity. PLS-SEM method is an effective model for quantitative assessment of the interaction of user opinions on factors related to operational improvement Continuous improvement of user opinion outcomes is a premise for future improvement ideas based on actual user surveys. The content using the PLS-SEM model to analyze user interaction factors in the results of improvement activities is the content that complements the PDCA cycle in the 7-step QC cycle in global quality improvement activities, following the idea of Lean Six Sigma.

Case study for continuous improvement

Process improvement (Wirkus & Chmielarz, 2018) means eliminating activities that do not add value or factors that cause waste and lead to unnecessary costs, making the cost of outsourcing products increase. Realistically, is to reduce the competitiveness of enterprises. Lean Six Sigma with DMAIC (Define – Measure – Analyze – Improve - Control) cycle is a powerful tool in continuous improvement operations, the results of continuous improvement activities bring tangible cost reduction results and processing costs, improve product quality, and improved customer satisfaction (Krishna et al., 2019). In this study, the 10-step QC cycle was improved by combining the DMAIC cycle in Lean Six Sigma and the powerful experimental design Taguchi, digital numerical control, and computer vision using artificial intelligence (AI) technique into the tool improvement activities in the machining line by Minitab 18.0, MATLAB 2022a and smart PLS 3.0 software. Simple software and methods are easy to set up and use on the machining line and are also accessible to machine operators in continuous improvement. Research to improve overall machining line efficiency (OEE), line productivity (Kauppila et al., 2020), waste generation, and machine operating time are the top 3 goals in research to improve productivity, and processing capacity as well as reduces waste products. The main activities in the research are carried out in the following order of content: (1) Inspect, confirm, and evaluate the entire production process of the processing line from the beginning to the end of the process. (2) Detailed assessment at each processing stage at each step of product processing using industrial tools. (3) Determine waste factors arising in the processing line.

The main job of continuous improvement is to eliminate wastes arising in the operation process and to reduce the inefficient activities of each machining stage in the manufacturing process of mechanical components. Eliminate downtime, reduce waste, and eliminate post-machining corrections. Research on improving the productivity of mechanical product processing lines has been studied by many authors before, from those research results, show opportunities to improve product productivity and at the same time improve product quality. Apply to lean six sigma tools such as the DMAIC cycle and industrial tools to analyze the status quo, reduce, and control conditions for continuous improvement. Continuous improvement activities are carried out according to the new 10-step QC cycle combining Taguchi's powerful empirical research and Anova analysis analyzed from Minitab 18.0 software to optimize parameters for machining conditions as well as processing conditions. determine the optimal parameters for tool design improvement activities in the mechanical processing line. In fact, The experimental design of Taguchi and Anova analysis for the tool line of turning machining tools based on the material named SKD11 and the results after parameter optimization (Kotliar et al., 2020) and improvement of product surface machining tools at the surface turning line. Product surface eliminates lapping and surface repair, Labor cost is reduced by 574usd/month, tool cost is reduced by 93usd/month, the jig investment cost is 35 usd/month, the end of result is reduced waste the cost in terms of cost is 632 usd/month, calculated per year, reducing the processing cost for the line is 7 584 usd/year.

The main stages of improvement activities carried out to achieve the above results are performed according to the following steps: stage 1 (identify and measure) using Pareto charts and process analysis capability Processed by human-machine interaction flowcharts from industrial tools to identify waste factors (Rewers et al., 2019) in on-line machining operations. Phase 2 (analysis) applies tools in lean six sigma and industrial tools to analyze the current status of implementation according to the "Best of Best" and "worse of worse" theories. phase 3 (improvement) application of powerful experimental design tool Taguchi through orthogonal networks and ANOVA analysis using Minitab 18.0 software and finally, implementation of control plans to ensure sustainable profits.

Connecting and deploying research results from academics at institutes, research centers, or universities into a practical environment is an urgent requirement, easy to implement, and everyone can apply. Research results into practice is a bridge that all researchers need to pay attention to first. This study also brings the idea of research, implementation of research methods, and results into practice. Minitab 18.0 software is easy to install on the computers at the production line. Using this software to implement experimental analysis according to the powerful experimental research model Taguchi as well as ANOVA analysis. Similar to smartPLS 3.0 software, it is also simple to install and operate, analyze the survey results of operators and maintenance specialists, maintain tools and post-improvement machines, and identify key elements or factors, and content as a prerequisite for future research improvement.

Methodology and experimental results

Improved QC cycle is a 10-step method improved from a 7-step QC cycle, improved based on the PDSA cycle, combining 2 cycles, PDCA and PDSA. The improved QC model is shown in the figure below (Fig. 6).

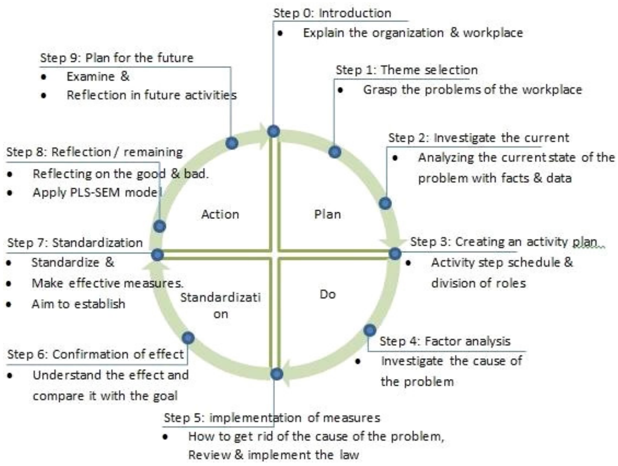


Fig. 6. Improve QC Cycle

Lean Six Sigma (DMAIC: Define-Measure-Analyze-Improve-Control) combined PDCA cycle (Plan-DO-Check-Action), see Table 2.

Table 2
Integrate DMAIC phase into PDCA cycle

Plan	Do	Check	Action
Define & Measure phase	Action phase	Improve phase	Control phase

Define phase: Capturing problems through data collection and processing parameters at the production line utilizing input signal acquisition devices such as checking sheets, barcode systems, and electrical receivers digital or analog signals as a source to analyze and identify anomalies or wasteful activities at the mechanical product processing stage. Lean Six Sigma tools in particular Pareto charts, and histograms to identify problem points. The problem of activities that bring bad results for the machining line, at the finished processing stage, generate a non-standard surface roughness Ra0.4 max with a frequency of 100%, giving rise to the lapping process using sandpaper with a high degree of resolution of 1000 and 2 employees respectively for 2 shifts and 1 lapping machine to correct the surface roughness of the product with a frequency of 100%. This is a wasteful step that does not bring value increase, corrective action is required, see Fig. 7.

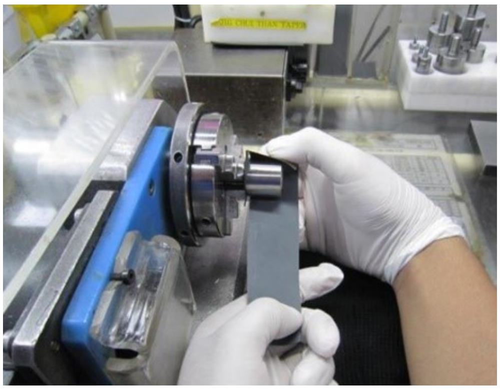


Fig. 7. Lapping by hand

From the above analysis results, clearly identify the problem causing waste as a premise for setting improvement goals to continue the experimental design steps to determine the problem point. as well as clarify the optimal parameters for improvement activities to eliminate lapping and wasteful stages. Gant chart outlines the overall plan for improvement and WBS (Work Breakdown Structure) diagram details the steps to be improved, clearly shows the completion time of each job, and clearly specifies the members. responsible for implementing the tool improvement work and the results will be tracked from the detailed plan sheet (WBS) and master plan sheet, Gant chart. Determine the parameters, processing conditions, and overall quality management specifications of the processing line from the product quality management regulation table called control plan and the risk management table of the stages machining called FMEA (Failure Mode & Effect Analysis) to verify the initial parameters before taking improvement actions. from the results of design parameters of the machining process as the basis for data analysis are recorded, collected in real-time at the machining line, using tools in lean six sigma such as control charts, graphs, and charts. histogram, scatter plot to identify anomalies and determine the process capacity parameter Cpk1.33 min for surface roughness size Ra0.4 max analyzed and calculated by histogram using Minitab 18.0 software. man-machine interaction flowchart from industrial tools analyzes operations from video back to each processing stage in the line and identifies wasteful, non-value-added operations, details the time taken on each operation, at each employee's move, evaluates the overall processing time to complete a product on the processing line, the value from the analysis results from the human-machine interaction flowchart as the database initial data to verify the results after actual improvement activities at the machining line. Investigate the cause of the problem. The root cause of wasted steps in the machining process is identified from the analysis results of the fishbone diagram and the 5 why analysis.

Measure phase: The point of waste arising in the machining line has been clearly identified as the lapping stage and carefully analyzed for the causes arising at the finishing stage, resulting in uneven roughness. Satisfying the requirements Ra0.4 max is due to the roller incompatibility in terms of hardness, and the frictional pressure between the roller and the product surface. The roller shaft is attached to the electric cylinder (Fig. 8), and the control circuit uses a 3-phase 230 voltage source.

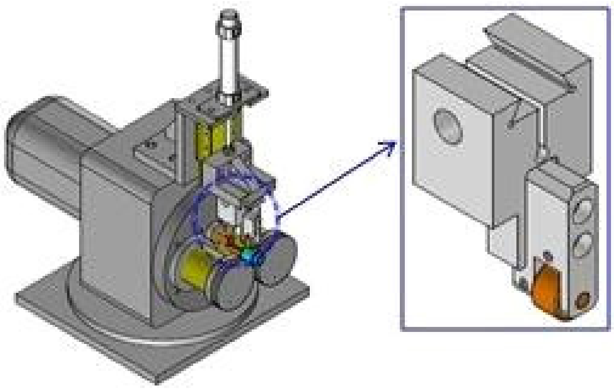


Fig. 8. Roller system diagram

Expected geometric distribution (Eq. (1)) using stability analysis to supply power to electric air cylinder, run test 1000 cycles with a probability of voltage instability $= 10^{-3}$, calculate obtained standard deviation $\sigma = 999.5$ and expected $E(N) = 1000$. In conclusion, this very high standard deviation $\sigma = 999.5$ indicates that the power supply to the electric cylinder is unstable, indeed with acceptance level $\alpha = 0.05$, percentiles $N_{0.05} = 52$ and $N_{0.95} = 2995$

$$E(N) = \frac{1}{P} \tag{1}$$

Unstable power quality causes the electric cylinder driver to lose signal frequently and causes the roller mechanism to vibrate, causing the contact surface between the roller and the product to change frequently, resulting in poor surface roughness.

Analysis phase: At the processing line, many smart electrical devices such as led lights, desktop computers, and smartphones are used, which are the main causes of harmonics in the power supply. Test of univariate analysis of harmonics in the power source that makes the power cylinder unstable, Eq. (2)–(4).

$$SS_T = n\sum_{i=1}^{a}(\overline{y}_i - \overline{y})^2 \tag{2}$$

$$SS_E = \sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij} - \overline{y}_i)^2 \tag{3}$$

$$F_0 = \frac{\dfrac{SS_T}{(a-1)}}{\dfrac{SS_E}{(N-a)}} \tag{4}$$

Experimentally run 5 levels of harmonic noise in the power supply and run it 5 times on each harmonic level and hypothesize H_0: Unstable power quality does not cause the electric cylinder to vibrate and scratch the product surface, hypothesis H_1: Unstable power quality Causes the electric cylinder to vibrate and scratch the product surface. Eq. 2–4 gives the results of the statistical analysis function $F_0 = 14.76$, with the acceptance level $\alpha = 0.05$, look up the statistical table with $F_{0.05,4,20} = 2.87$ and $F_0 = 14.76 > F_{0.05,4,20} = 2.87$ and $\alpha = 0.05 > P$-value $= 0.01$. In conclusion, H_0 is rejected, there is a difference between the treatments and the power quality is unstable due to the harmonics generated, causing the roller vibration error to scratch the surface of the product.

The multivariable experimental design model analyzes the vibrating roller factor (a) and the hardness factor of the roller material (b) causing scratches on the product body. A two-variable experiment with the roller vibration factor is divided into 3 levels and the material hardness of the roller is divided into 3 levels, and each experiment is performed 4 times, the total number of experiments is 36. Hypothesis H_0: The vibration of the roller and the material hardness of the roller do not cause scratches on the product surface and Hypothesis H_1: The vibration of the roller and the material hardness of the roller cause scratches on the surface of the product. The results of the two-variable empirical analysis (Table 3).

Considering the impact level of a factor, p-value $= 0.002 <$ acceptable level of $\alpha = 0.05$. In conclusion, H_0 is not accepted, factor a has the effect of causing scratches on the surface of the product. Considering the impact level of b factor, p-value $= 0.000 <$ acceptable level of $\alpha = 0.05$. In conclusion, H_0 is not accepted, factor b has the effect of causing scratches on the surface of the product. Considering the level of interaction between factor a and factor b, p-value $= 0.01 <$ acceptable level of $\alpha = 0.05$. In conclusion, H_0 is not accepted, factors b and b have the effect of causing scratches on the surface of the product, but elements a and b do not interact.

Table 3
ANOVA for two-variable experiment analysis

SOV	SS	DOF	MS	F_0	P
a factor	10.68	2	5.34	7.91	0.002
b factor	39.12	2	19.56	28.97	0.000
interactive a&b	9.61	4	2.40	3.56	0.01
Error	18.23	27	675		
Total	77.65	35			

Univariate analysis of experimental variance (Eq. (2)–(4)), with 5 different levels of material hardness of the roller and each level of hardness run 5 times. (The product uses SKD 11 material, hardness 58 ∼ 62 HRC, 5 degrees of roller material SS400 hardness are 58, 60, 62, 64, 66 HRC). Hypothesis H_0: The hardness of the roller material does not cause scratches on the surface of the product. Hypothesis H_1: The hardness of the roller material causes scratches on the product surface. With statistical significance level $\alpha = 0.05$, look up the statistical table for the results of the statistical function $F_{0.05,4,20} = 2.87$ and the statistical function calculated from the observed sample gives the result $F_0 = 10.21$. In conclusion, H_0 is rejected. The P value from the analysis of variance results is $0.002 <$ the hypothesis acceptance level $\alpha = 0.05$. Conclusion H_1 is accepted, the hardness of the material causes scratches on the surface of the product. It gives rise to an unsatisfactory roughness or an unsatisfactory visual error, giving rise to a step that does not bring added value, which is the lapping stage. That means costs about \$7 584 per year. It is necessary to determine the optimal parameters for the machining conditions at the finishing stage.

Improve phase: The expected value decision-making technique selects the optimal improvement option based on inputs such as the present value of the option (PW), the probability of the non-positive present value of the options $P(PW < 0)$, expectation and present value variance of the options $E(PW)$, $V(PW)$. Probability of occurrence of enumeration state according to vector P (Eq. (5)) and expected utility when choosing option a_j (Eq. (6)).

$$P = \{p(s_i), \quad i \in N_m\} \tag{5}$$

$$E(u_j) = \sum_{i=1}^{m} u_{ij} p(s_i) \tag{6}$$

Improve the surface quality of the product to ensure the roughness size is smaller than Ra0.4Max, 4 options are proposed. Option 1 (A1): Periodically train bonded inspection staff to remove scrap. Option 2 (A2): Schedule periodic maintenance of the roller and the 3-phase 230 voltages supply system for the electric cylinder control circuit. Option 3 (A3): Research and replace new materials for Rollers compatible with machining conditions and Option 4 (A4): Install a device to filter out harmonics at the source and install a smart meter to measure power quality in real-time (see Table 4).

Table 4
Analysis results of 4 options

Options	$P(PW < 0)$	$E(PW)$	$V(PW)$
A1	0.3	1000	6
A2	0.2	1000	4
A3	0.0	1000	2.5
A4	0.2	1500	3.4

The expected factor with the largest price is the optimal solution, the plan A4 has 1500 as the largest, followed by A1, A2, and A3 with the same expected value of 1000. The solution with the lowest probability is the optimal solution, the alternative A3 with a probability of 0.0 is the lowest, followed by the alternative A2, A4 with the same probability of 0.2, and finally the alternative A3, the lowest variance is the optimal solution, A3 has the lowest variance and is 2.5, followed by A4 with 3.4, A3 with 4, and last. same option A1. Option A3 was selected as the priority option for implementation, followed by Option A4.

The TAGUCHI technique is applied to option A3, the goal of TAGUCHI design is to create a design with parameters such that the product or process operating with this set of parameters will be affected by the least confounding factors, see Fig. 9.

The expected result is a reduction in process variability and a reduction in the sensitivity of confounding factors to the product. Roller design is based on 4 factors such as (1) material type (SS400 and Urethane Steel), (2) Material hardness (58–62), (3) MG815 coolant oil concentration (3–5%), and (4) roller width (3–10). The type of design is a 2-level design, several factors are 4, and signal noise ratio is smaller is better, see Fig. 10. In the response level analysis results,

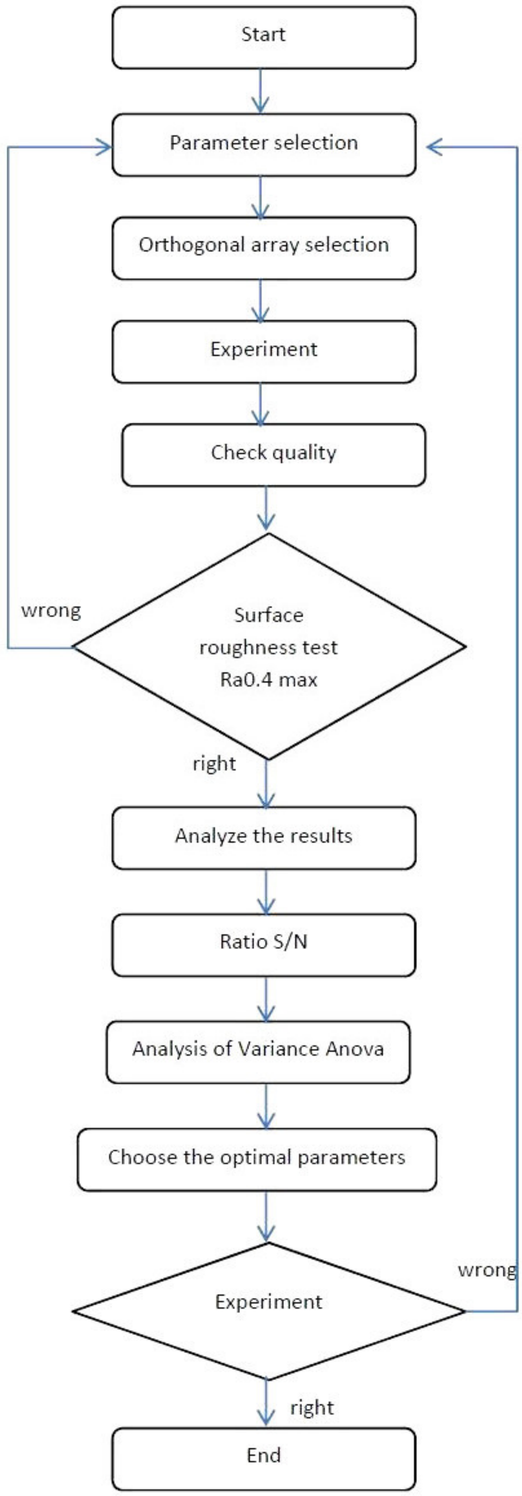


Fig. 9. Roller parameter optimization process

material hardness is the leading factor to consider, the second is type of material, the third is the concentration of MG815 oil, and finally the roller width. Considering Coefficient for SN ratio, P value of Urethane material = 0.001 < 0.05. In conclusion, Urethane material gives good results in terms of response.

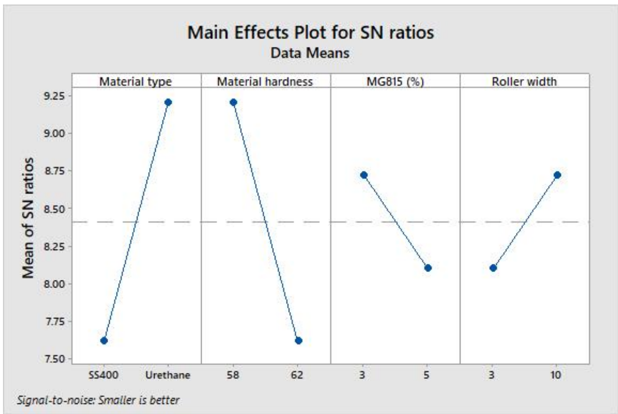


Fig. 10. Signal to noise ratio analysis

Option A4 redesigns the power supply circuit diagram, adding a TAC-50-223 type harmonic receiver in front of the electric cylinder control circuit, see Fig. 11.

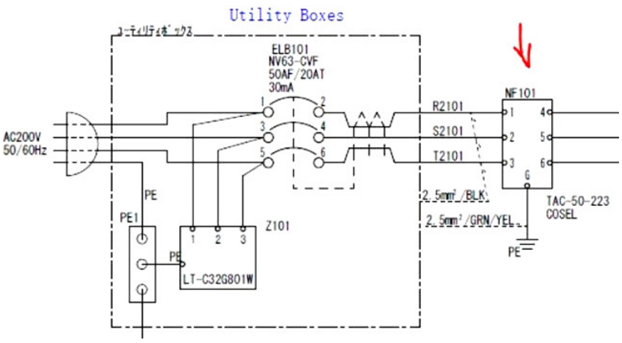


Fig. 11. Harmonic mitigation improved the diagram

The smart meter is connected to the power circuit after attaching the harmonic filter, the power measurement results are connected to the measurement system by the digital numerical control (DNC) technique. Power measurement results are monitored in real-time and harmonic components are controlled according to IEEE 519. The total harmonic distortion (THD) value is outside IEEE 519 standard, the measurement system generates an alarm signal.

The improved pre-system consists of the SS400 roller material, with no mains harmonic interference filter and no real-time power quality meter, see Fig. 12.

The post-improvement system includes Urethane roller material, has a power supply harmonic noise filter, and has a real-time power quality meter, see Fig. 13.

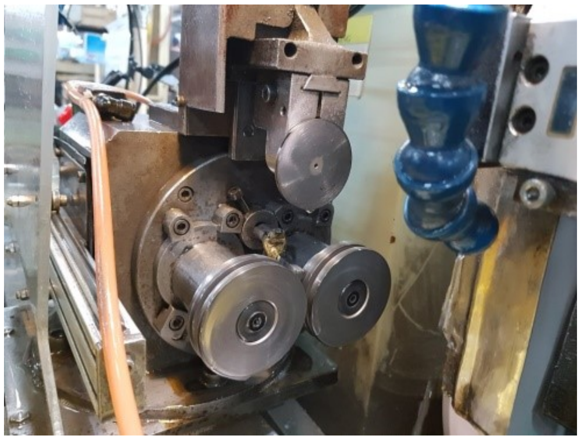


Fig. 12. Roller SS400 material

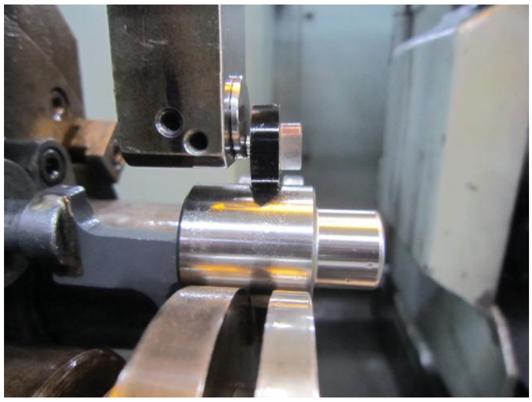


Fig. 13. Roller Urethane material

The test of expectations when knowing the variance is applied to test the system after the improvement has a good response, the rejection area of the hypothesis H_0 is shown by formula (7).

$$\overline{X} < \mu_0 - Z_{\alpha/2,\sigma/\sqrt{n}}\,, \quad \overline{X} > \mu_0 + Z_{\alpha/2,\sigma/\sqrt{n}} \qquad (7)$$

The machine system runs 50 products continuously and the calculated sample mean is 0.36 and the sample standard deviation is 0.2. Hypothesis H_0: The improved system results in surface roughness of less than 0.4. Hypothesis H_1: The improved system results in surface roughness greater than 0.4. With the hypothesis acceptance level $\alpha = 0.05$, the calculated rejection area of hypothesis H_0 is less than 0.3 and larger than 0.7. In conclusion, hypothesis H_0 is accepted, and the improved system meets the expectation of surface roughness Ra0.4Max.

The test of expected deviation according to the student distribution applies the post-improved system application expectation test on 2 different machining machines, the sample mean deviation (Eq. (8)), and the value of the rejection area of the hypothesis H_0 (Eq. (9)).

$$\frac{\left(\overline{X}_1 - \overline{X}_2\right) - (\mu_1 - \mu_2)}{S\sqrt{\dfrac{1}{n_1} + \dfrac{1}{n_2}}} \sim t_v \tag{8}$$

$$\begin{aligned} &\left(\overline{X}_1 - \overline{X}_2\right) < -t_{\alpha/2,v} S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}, \\ &\left(\overline{X}_1 - \overline{X}_2\right) > -t_{\alpha/2,v} S\sqrt{\frac{1}{n_1} + \frac{1}{n_2}} \end{aligned} \tag{9}$$

Using the same improved system, each machine runs 30 products, the mean deviation between the 2 samples is 0.36, and the variance between the 2 computers is 0.38. Hypothesis H_0: The improved system responds well and meets the requirements of product surface roughness Ra0.4Max. Hypothesis H_1: The improved system does not respond well and does not meet the requirements for product surface roughness Ra0.4Max, with the hypothesis acceptance level $\alpha = 0.05$, the hypothesis rejection area. The calculated H_0 is less than –0.4 and greater than 0.4. The sample means deviation between the two machines is not in the H_0 rejection region. In conclusion, H_0 is accepted, and the system after improvement meets well for 2 machines and ensures the quality of surface roughness is to reach Ra0.4Max.

The fuzzy synthetic evaluation model evaluates the stable operation of the system through fuzzy parameters such as system performance (P), system operating cost (C), availability. in the operation of the system (A), and the software application of the system (S). Set of fuzzy evaluation criteria C (Eq. (10)). Set of fuzzy rating scales X (Eq. eq11). The fuzzy relation matrix $C \times X$ (Eq. (12)) and the fuzzy evaluation standard weight W (Eq. (13)).

$$C = \{c_i,\ i \in N_m\} \tag{10}$$

$$X = \{x_j,\ j \in N_n\} \tag{11}$$

$$R\colon C \times X \to [0,\ 1] \tag{12}$$

$$W = \{w_i,\ i \in N_m\} \tag{13}$$

The rating scales are set as good (E), fair (S), average (A) and bad (I). A sample is evaluated according to the following matrix:

$$R = \begin{bmatrix} & E & S & A & I \\ P & 0.1 & 0.3 & 0.4 & 0.2 \\ C & 0.0 & 0.1 & 0.8 & 0.1 \\ A & 0.1 & 0.6 & 0.2 & 0.1 \\ S & 0.1 & 0.4 & 0.3 & 0.2 \end{bmatrix}$$

Standard weight vector $W = [0.4\ 0.3\ 0.2\ 0.1]$, integrated evaluation fuzzy set $E = W \times R = [0.1\ 0.3\ 0.4\ 0.2]$. The largest fuzzy set value is the selected optimal value and is 0.4. In conclusion, the operating system meets the average level, needs further improvement in terms of filtering harmonic components at the source, improving power quality and THD meets less than 5% according to IEEE 519 standard.

Control phase Quality control plan and re-evaluate risk factors in the machining line by updating the line risk control table (FMEA), conducting standard-setting guidelines to operate and train operator users and maintenance personnel, ensure that the post-improvement results are operated stably and with high results. Analyze, determine, and classify problem points according to the flow chart below (Fig. 14).

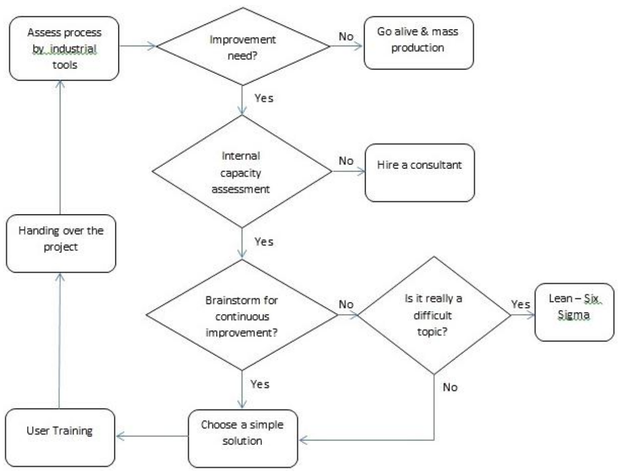


Fig. 14. How to select a good improvement program

The digital numerical control method connects the smart meter to the measurement system and establishes the THD management standard according to IEEE 519. Bar code on barcoded order call machining center program will activate system program operation measurement system and current quality measurement data are checked and data saved into SQL system in real-time, big data on 230 voltage 3-phase power quality measurement results is the data source Report to managers, scientific researchers to analyze and make decisions to develop electrical energy management systems in industrial plants. THD value is less than 5%, and the measurement system considers it to be a pass and takes the next step. In the opposite case, if the THD value is greater than 5%, the measurement system considers it does not pass and the measurement system is locked.

The digital numerical control method is used to establish a measurement system at each machining stage on the entire machining line. Online data management measurement system to manage product quality, quality management of operating conditions (power quality 230 voltage 3-phase, quality of setting up cutter coordinates, quality of cooling water,...) in real-time, following the theory of total quality management.

Computer vision technology uses artificial intelligence (AI) technology to recognize objects according to the color discriminations of the roller's material classification. Roller used SS400 steel material with white color and was taken 500 pictures in different aspects, 70% of 500 pictures were used for training and 30% of 500 pictures were used for testing for color recognition computer vision system, iron material, and do the same for the black Urethane roller and also take 500 pictures from different angles 70% of the images are used for training, and 30% of the images are used to test the computer vision system. The local binary pattern technique is applied to accurately extract the features in the images of SS400 and Urethane, then, the K-nearest neighbor (K-NN) technique is used to identify the extracted features to classify the Urethane roller available in black and Roller SS400 in white. Starting to process the first product, the camera takes pictures of the roller and recognizes the color, the inspection system connects to the computer vision system to identify the current roller, the black roller (Urethane material) the correct identification system, and for the machining center to continue to the next execution step and vice versa, the roller is white (SS400) the system is down and locked.

Discussion

Lean manufacturing has a strong focus on process improvement, eliminating waste, and increasing overall process productivity (OEE). Six Sigma focuses on the output of the manufacturing process, emphasizing quality efficiency, and the goal of eliminating or reducing process variability to improve the quality of the product. The 10-step QC improvement method in the PDCA cycle is incorporated into the DMAIC chase (Sabry, 2020). Experimental research methods, Taguchi analysis, statistical hypothesis testing, and analysis of variance are used in the analysis. The software Minitab 18.0, MATLAB 2022a, and smart PLS 3.0 are used throughout the research process. Linking the operational steps in the in-process process is urgent. Quality control of each activity, elimination of redundant operations, and control of operations that depend on operator skills are essential activities. Control the variation of machining process parameters, improve the stability and accuracy in machining, and eliminate the activities or operations with the risk of generating waste products. Statistical testing method, measurement, and analysis of the results of the process data, quantitative analysis tools analyze the trend of the process change. The statistical hypothesis testing functions objectively verify the evaluation results based on the actual data collected at the respective processing line, the p-value is used as the main parameter to evaluate the test results. Statistical hypothesis in the acceptance region $\alpha = 0.05$.

Experiment Taguchi analyzes the impact conditions in machining such as cooling water concentration, hardness of roller material, and roller thickness and finds optimal parameters to choose the optimal material for roller manufacturing, results as a result, Urethane material is considered as the optimal material for roller production and does not cause scratches on the product surface. Product surface polishing is canceled, machining lead time is reduced, and surface scratches are no longer generated at the machining center stage, improving output. The result of voltage measurement is connected to the test system and saves the measurement data to the measurement system through the digital numerical control (DNC) technique, which evaluates the pass and not pass THD value of harmonics in the power supply automatically by the system, power quality measurement data is monitored in real-time. Check that the machining system uses the correct type of roller after improving, the roller using urethane material is black and the SS400 material is white, the computer vision machining system uses artificial intelligence (AI) technology to identify objects by color discrimination. The measuring system connects to the computer vision system and recognizes the pass not evaluate the roller used. The results of this study gave the following results: (1) Removal of surface waste products. (2) Shorten the machining process, and reduce machining lead time. (3) Research and experiment to replace manufacturing tool manufacturing materials, contributing to increasing tool life and increasing machining stability, increasing productivity, and eliminating waste products. (4) Applying digital numerical control (DNC) techniques, computer vision techniques using artificial intelligence (AI) to control machining operations, and setting up a smart factory. As a member of continuous improvement research at the company, I have always focused on activities to reduce machining costs and improve the satisfaction of users and machining line operators in terms of operational results. improve. After the improved research is put into application in the actual machining environment, it works in the experimental environment without any abnormal operation. In this study, the experimental results were directly performed by the operator himself, analyzed experimentally on Minitab 18.0 software together with technical staff.

Conclusions

This paper proposes to use a digital numerical control technique to connect 230 voltage 3-phase source voltage measurement data to the inspection system at the machining center, THD% value according to IEEE 519 standard is controlled and evaluated pass or not pass by the measuring system. Power quality values are saved as big data in real-time into the measurement system. The computer vision method uses artificial intelligence to recognize faces, and control the layout of the machining center operator's position according to the respective skill criteria. People with no training or skills in operating an uncertified machining center are recognized by the computer vision system and the measurement system at the machining center is locked. The computer vision system is also applied to check if the roller is used correctly according to the improved results. In case the SS400 (white) material type roller is detected to be used, the measuring system is locked.

Replace raw materials for making roller from SS400 material to Urethane material, install harmonic interference filter (TAC-4-30A) into 230 voltage 3-phase power supply for the electric cylinder control circuit, digital numerical control technique connecting power quality measurement data from smart meter to measuring system and saving data in real-time, computer vision technology uses artificial intelligence to control using the right type of roller and control the machining position. The result of the improvement is the elimination of lapping, the elimination of surface scratches, the reduction of machining lead time, and the reduction of line operator staff, resulting in total cost savings of $7584 per year. Transform the machining center from manual operation to fully automatic operation (smart process) and control machining conditions by measuring the system, creating a comfortable machining environment for operators, and simplifying operations.

The harmonics generated in the 230 voltage 3-phase power supply for the control circuit are even higher than the standard IEEE 519 (THD $< 5\%$), this is considered the biggest limitation of this study. A power quality measurement system connected to a smartphone that performs real-time monitoring and correction of power quality is also considered a promising future study. Computer vision uses artificial intelligence to check the quality of the product's appearance, the test results are assessed as pass or not by the measuring system, which is also a shortcoming that this study has not met.

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