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A case study on the application of Mahalanobis-Taguchi system for magnetic component

N.N.N.M. Kamil[1], S.N.A.M. Zaini[1] and M.Y. Abu[1]*
[1] Faculty of Manufacturing and Mechatronic Engineering Technology, Universiti Malaysia Pahang, 26600, Pekan, Pahang, Malaysia
**Email: areena5582@gmail.com*

Abstract- Control chart is a graphical record for visualizing the variations that occur in the central tendency and dispersion of a set of observations to achieve the process stability. The company under study mentioned that when the assignable causes have been eliminated from the process to the extent that the points plotted on the control chart remain within the control limits, the process is in a state of control or stable. Therefore, the company simply assumes that 10 parameters at magnetic component workstation are significant. However, by solely relying on the control chart to confirm the significant parameter is not sufficient. The purpose of the research is to emphasize on the SNR gain towards the magnetic component in production environment specifically visual mechanical inspection (VMI) at E&E industry. MTS works by classifying both normal and abnormal observations and optimize various parameters in workstation to produce better quality product. This work considered annual data of 2018. This work found that positive gain through signal to ratio (SNR) indicated the quality of system still in good condition from January with 0.3298 until December with 0.3667 after insignificant variable have been removed. This work also suggested height of excess plastic header as one of variables in VMI should be removed since the variable does not contribute to the system as shown in 2018. Meanwhile, there are two parameters reduced in March (Number of epoxy spot on winding coil and height of excess plastic header), July and August (Condition of marking and height of excess plastic header) and November (Number of scratches and height of excess plastic header). This concluded that MTS is a practical method for classification and optimization in the industry.

Indexed Terms- Mahalanobis-Taguchi system, magnetic component, Mahalanobis distance, SNR gain

I. INTRODUCTION

Industrial Revolution in modern history is a process of change from an agrarian and handicraft economy to one dominated by industry and machine manufacturing. As factories became widespread, additional managers and employees were required to operate them. There are four revolutions of industry started from Industrial Revolution 1.0 until Industrial Revolution 4.0. The overview of these industrial revolution was reported by Jeevita and Ramya [1], whereby the first Industrial Revolution began in the middle 18th century and was brought on by the invention of the steam engine. It was the reason for the creation of a new type of energy that later on helped speed up the manufacturing of railroads thus accelerating the economy. In Industrial Revolution 2.0 which was started at the beginning of 20th century, electricity became the primary power source to all factory activities and processes. As the machines are designed with their own power sources, they become portable and easy to handle. Industrial Revolution 3.0 began in the last decades of the 20th century. Two major inventions such as programmable logic controllers and robots helped give rise to an era of high-level automation. Consequences, it provides the opportunity to replace operators with automated machine. In the 21st century, Industrial Revolution 4.0 is a smart industry that marries physical production and operations with smart digital technology, machine learning, and big data to create a more holistic and better connected ecosystem for companies that focus on manufacturing and supply chain management. There are nine pillars of the Industrial Revolution 4.0 as reported by Erboz G. [2] which outlined the new technology manufacturers. They are used to improve all areas of production processes including big data, autonomous robot, simulation, cyber security, Internet of Things, cloud computing, additive manufacturing, augmented reality, and system integration. With improvement in the system integration, companies can become more interconnected both externally and internally. This will result in an agile manufacturing environment allowing real time production corrections for better economy development. Thus, the Malaysian Ministry of International Trade and Industry (MITI) tabled the National Policy for Industry 4.0 to help advance the countries' businesses and factories. This will ideally help the local industries to develop new skills and talent with the people and to also increase efficiency, quality and productivity. Malaysia is the world's seventh largest exporter of electric and electronic products with a total export of MYR287.7 billion. In fact, this sector provides the intermediate or auxiliary products and components which contributes towards the execution of Industrial Revolution 4.0. The growth prospect of electrical and electronic industries in the country depends on the adoption of smart manufacturing processes and technologies. As reported by Malaysia Investment Development Authority (MIDA), the return of investment might not be obvious in the short term, but the companies will attain great and efficient performance, improving the quality of the production and labour skills. The government expects the electrical and electronic sector to create incremental gross national income impact of MYR53.4 billion and 157,000 new jobs by 2020 which riding on the growth prospects of the global industry. As documented in 11th Malaysia Plan (2016 – 2020), electrical and electronic sector is one of the major sub-sectors that will energize the manufacturing sector in producing higher value-added and complex products. Therefore, quality of product is really important to sustain the business. This work is expected to offer SNR contributions to the current literature by providing an additional evidence and information on the impact of MTS to the industry.

The Mahalanobis Distance (MD) was developed in 1936 by a well-known Indian statistician Prasanta Chandra Mahalanobis to classify members of a group described by characteristics, taking into consideration the system's correlation structures which can, or can not, be correlated. Su C.T. and Hsiao Y.H. [3] said that in the 1950s, in order to improve the engineering efficiency calculated in terms of deviations from the ideal standard performance, Genichi Taguchi had created Taguchi's robust engineering. Taguchi G. and Jugulum R. [4] proposed that Genichi Taguchi then incorporated the concept of a comprehensive engineering Mahalanobis-Taguchi System (MTS) by providing a way of identifying the reference group and of measures for individual observations of anomalies. Then, a case study entitled "Mahalanobis Distance for Diagnosis and Pattern Recognition System Optimization Procedure" from Taguchi S. [5] had applied the MTS for the diagnosis of liver disease in Tokyo, Japan with 15 variables and developed an 8 step procedure for diagnostic and pattern recognition problem. Basically, the MTS is a "pattern recognition technology that aids in quantitative decisions by constructing a multivariate measurement scale using a data analytic method". Woodall W.H. et al. [6] have discovered that multivariable statistics must be available on "normal" group and on a certain number of "abnormal" items which often can be divided into classes depending on the abnormality rates. In this approach, MD as a discriminant analysis approach is employed in assessing the similarity, determining and evaluating different patterns in regard to the reference space mean, based on the correlations between variables. MD is then used in the development of a measurement scale to estimate accurately in multidimensional systems. The MTS technique mainly consists of three stages. In the very first stage, selects the reference space that is a benchmark group of normal data and measures their MD for each sample. Anomalous data must be detected in the second stage. The larger MD values from standard abnormal data showed the scale to be fine. In the end, Genichi Taguchi proposes an optimization technique as explained by Taguchi G. and Jugulum R. [4]. The orthogonal array and the S/N ratio may be used to decrease the number of variables after the evaluation of contribution of each variable on factorial effect graph. Cudney E.A. and Corns S.M. [7] identified that the benefit of MD is that the associations between any variables during the normalization process and very economical for multidimensional model recognition systems are taken into account. The method is effective because the MD values for detection and isolation are remarkable as long as their differentiation is clearly isolated, as said by Wang Z. et al. [8]. Wang Z. et al. [9] also mentioned that there are also no computational criteria required for the measurement of MD values, so that the method can be used in real time. Since the MD value is determined by the standard deviations from the mean of the samples, a statistical measure as proposed by Cudney E.A. and Corns S.M. [7] is taken of how well an unknown sample suits or closers to a specified sample set. Cudney E.A. et al. [10] identified that MTS also recognises significant factors of a multivariate system, because the Taguchi methods reduce redundant characteristics and extract the main components very effectively as said by Wang Z. et al. [8]. MTS can therefore be adapted to boost industry growth, especially for high-tech quality checks, without losing its process quality. Woodall W.H. et al. [6] said that there has been little emphasis on philosophical, organizational and technological problems to reveal the limitations of MTS as follow:

Conceptual:

MTS is considered as ad hoc since no underlying mathematical principle is used in the method. Based on Taguchi G. and Jugulum R. [4], the MTS did not compare with other statistical multivariate, but only claimed that its method differs greatly. The distribution of the input variable is not assumed. For example, data vectors are not assumed to be normal multivariately. The results, numerical fluctuations or the predicted losses do not include any probability distributions.

Operational:

Since normal or abnormal items are not easily distinguishable, it would appear that misclassification probabilities should be weighed, which is not feasible under the MTS system, to avoid the use of probability. There are no organizational meanings that are "higher than" However, it is not a valid run for all factor at their low rates, since at minimum one variable requires to be used for analysis. There can not utilized an OA containing this run.

Technical:

Taguchi G. and Jugulum R. [4] verified that unity for normal items is the average value for MDs. In the sense of the assumption that the average vector and the variable covariance matrix are multivariate normal and estimated, Abu M.Y. and Jamaludin K.R. [11] said that unity was not stated.

Based on the current observation through published works specifically MTS application as shown in Figure 1, there are seven areas can be categorized which are manufacturing, health care, information technology, agriculture, academic, automotive, and others. The largest proportion which is 32% in manufacturing area, while the lowest is agriculture with 3%. The percentage of health care is 8%, academic is 11%, automotive is 18% and information technology application and the others application is 14%. There are several works related to MTS. Abu M.Y. et al. [12] applied MTS to the big-end diameter of connecting rod to distinguish between two distinct ranges within the re-manufacturability process spectrum. The data collection on the main journal diameter crankshaft has been systematically analyzed from Abu M.Y. and Jamaludin K.R. [13]. The structural pattern recognition using MTS has been established from Abu M.Y. et al. [14] through the design of a scatter diagram that could help decision-making in a particular industry for 14 main crankshaft journals belonging to seven engine models with various sample numbers. Abu M.Y. et al. [15] classified crankshafts' end life into recovery operations based on the MTS. Nik Mohd Kamil N.N. and Abu M.Y. [16] and Abu M.Y. et al. [17] developed a distinctive crankshaft design and defined critical and non-critical crankshaft parameters depending on the MTS, then implemented the Activity-Based Costing (ABC) as a tool of approximation for crankshaft reprocessing costs. The criticality of end-life crankshaft parameters dependent on the orthogonal array of Taguchi was assessed in Abu M.Y. et al. [18]. Instead measure the costs by taking the critical parameters into account using conventional cost accounting. Azmi I.I. et al. [19] measured the degree of abnormality using MTS and diagnosed the parameters that influence the system. Nik Mohd Kamil N.N. et al. [20] and Mohd Safeiee F.L. et al. [21] implemented both MTS and Time-

Driven Activity-Based Costing in electric and electronic industry to evaluate the significant parameters and develop time equation and capacity cost rate respectively.

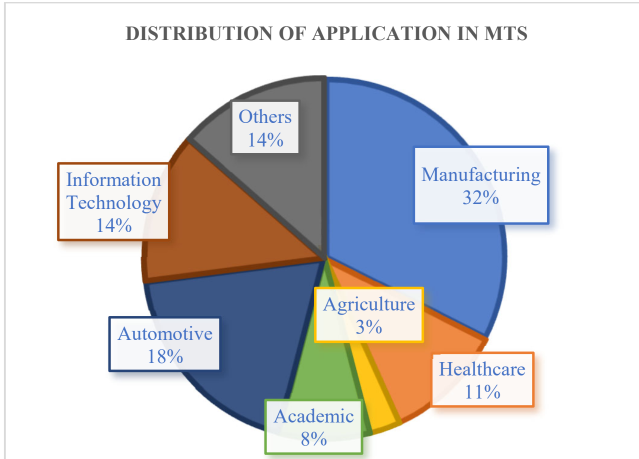

Figure 1: Distribution of MTS application

II. METHODOLOGY

The E&E industry is one of Malaysia's leading industries which contributed 24.5 percent in manufacturing sector production. Malaysia also is a leading contributor in the global E&E chain. This work has been conducted at XXX Sdn. Bhd. as a global provider of electronic component for critical performance solution. Since the industry received a big demand on the magnetic component from customers, this work selected that component as a subject matter as shown in Figure 2.

Figure 2: Magnetic component (Model:HA00-005587LFVT)

According to Ghasemi E. et al. [22], MTS is divided into four stages:

Stage 1: Development of measurement scale with the Mahalanobis space (MS) as a guide. Data are gathered from healthy products for the normal set of data. Mahalanobis distance (MD)s that constitute reference space is known as MS as shown in equation (1). The value of MDs is around one.

$$MD_i = \frac{1}{n} z_i C^{-1} z_i^T \tag{1}$$

where $z_i = [z_{i1}, z_{i2}, \ldots, z_{in}]$, can be defined as transpose vector of z_i, and C^{-1} is the inverse of the covariance coefficient matrix C.

Stage 2: Validation of MS. Observation of abnormal condition are selected out first. Their data sets are standardized with the mean and standard deviation from the usual data set. The MDs are then measured using the normalized function data and the normal data set covariance coefficient matrix. In other words, these abnormal MDs will have higher values. Hence the MD will be considered as out of MS due to the irregular condition.

Stage 3: Optimization. Orthogonal arrays (OAs) and signal-to-noise (S/N ratios) will be used to choose the useful features. OAs are used to identify the main characteristics by minimizing the various combinations of original characteristics. OA_{12} is used to identify the significant parameters. The number of columns in OAs will vary accordingly. There are two levels factors that consist in OAs which are level 1 and level 2. Level 1 can be described as used which means including the feature in the calculation while level 2 can be described as unused which means excluding the feature in the calculation. The S/N ratios calculated only using the abnormal condition.

Stage 4: Diagnosis and prognosis. In this stage, MS has reconstruct and tracked product MDs are determined using the useful features described in stage 3. If the value of MDs is within the MS, the monitor product will consider the normal product while the value of MDs is out of MS, the product will consider exhibit abnormal behaviours. In a conclusion, the higher the MDs, the greater the difference is between the product tracked and the normal product.

Definition of data is a group that collect information to prove the research objective. In the process of final VMI, the parameter of magnetic components can be classified according to its types: categorical data and numerical data. The first type of parameter, numerical data, is represent the collected data belongs to parameter than can be measured and counted. The second type of parameter, categorical data, is defined the collected data belongs to parameter characteristic and condition of magnetic component. There are 10 parameters of magnetic components in classification of categorical and numerical data which are number of scratches, height of insulator wire, condition of stripping, number of epoxies at header corner, number of spots on winding coil, condition of marking, distance of winding gap, height of excess plastic header, and level of tinning. Table 1 showed the numerical data parameters and its limits including lower limit for a good component in normal condition and upper limit for a rejected component in abnormal condition. There are six parameters in classification of numeric data, number of scratches, height of insulator wire, number of epoxies at header corner, number of spots on winding coil, distance of winding gap, and height of excess header. These upper and lower limits are provided at the production line of magnetic component.

Table 1: Parameters and limits of numeric data

Parameter	Lower limit (Normal)	Upper limit (Abnormal)
Number of scratches	0-3	>3
Height of insulator wire	<1.30	>1.30
Number of epoxy at header corner	1-3	4
Number of spots on winding coil	0-3	>3
Distance of winding gap	>3	<3
Height of excess	<1.30	>1.30

As shown in Table 2, there are four parameters in classification of categorical data, condition of stripping, condition of marking, type of coating damage, and level of tinning. The limits of categorical data are depending on the criteria either to reject or accept the component.

Table 2: Parameter and limits of categoric data

Parameter	Lower limit (Normal)	Upper limit (Abnormal)
Condition of stripping	Consistent and smooth of quality wire (1) No scratch at enamel surface (2)	Fluttering and rough of quality wire (3) Scratch enamel surface (4)
Condition of marking	No flux on the component (1) Clearly part number marking (2)	Yellowish marking (3) Melted bobbin (4)
Type of coating damage	No scratch at core coating (1) Has small hole at coil coating damage (2) Not exposed grayish powder on coating surface (3)	Scratch at core coating (4) Large hole at core coating (5) Exposed grayish powder on coating surface (6)
Level of tinning	No tinning level at wire (1)	Over tinning wire (2) Insufficient tinning wire (3)

Figure 3 shows the flowchart of the proposed methodology for the data analysis of MTS.

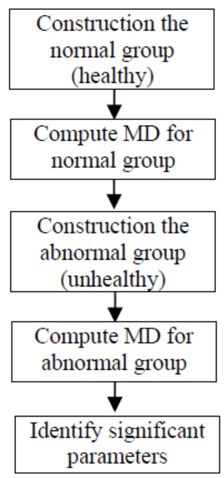

Figure 3: Flowchart of data analysis of MTS

III. RESULT AND DISCUSSION

Based on collected data set, there are different samples number for 10 parameters had found in normal condition for 12 months. Eventually, mean, standard deviation, correlation coefficient inverse matrix of normal samples is used as a basis to construct MS value. Table 3 shows the normal raw data of 24 January. In this work, 4589 samples are found in normal condition for all parameters that meet requirement of normal limit in production.

Table 3: Normal raw data of 24 January

Sample no	Number of scratches	Height of insulator wire	…	Height of excess plastic header	Level of tinning
1	1	1.25	…	1.25	1
2	3	1.25	…	1.25	1
…	…	…	…	…	…
4588	1	1.27	…	1.27	1
4589	2	1.27	…	1.27	1

Table 4 shows the raw data of abnormal condition of 24 January. In this work, 411 samples are found in abnormal condition for all parameters. As an example, for sample number 1 and 4, the parameter of rejected belongs to the number of scratches.

Table 4: Abnormal raw data of 24 January

Sample no	Number of scratches	Height of insulator wire	…	Height of excess plastic header	Level of tinning
1	4	1.27	…	1.25	1
2	4	1.27	…	1.25	1
…	…	…	…	…	…
410	2	1.33	…	1.27	1
411	1	1.26	…	1.27	1

Figure 4 illustrates the graph of MD normal and abnormal. The normal MD indicates the yellow graph while the black graph indicates the abnormal MD. Based on the result, the threshold normal MD (0.386806-2.077525) and the abnormal threshold MD (1.335044-6.782965). The SNR gain shows the value 0.3298. It means in positive gain.

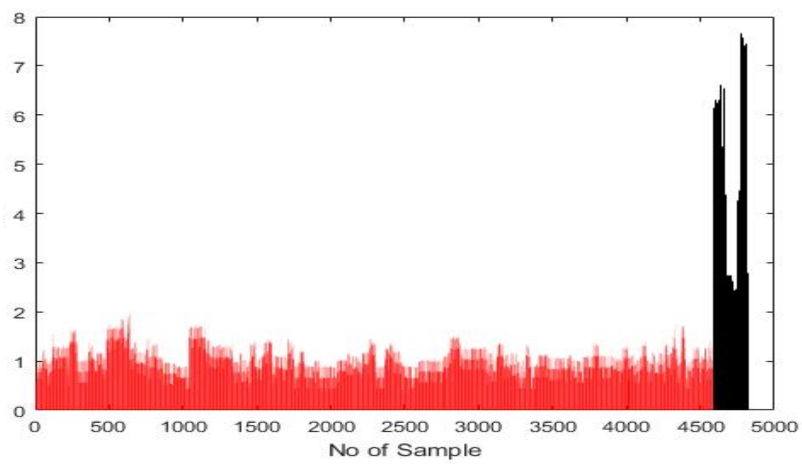

Figure 4: Normal and abnormal MD of 24 January

Table 5 shows the raw data of normal condition in 3 February. In this work, 4560 samples are found in normal condition for all parameters that meet requirement of normal limit in production.

Table 5: Normal raw data of 3 February

Sample no	Number of scratches	Height of insulator wire	…	Height of excess plastic header	Level of tinning
1	3	1.27	…	1.27	1
2	1	1.27	…	1.27	1
…	…	…	…	…	…
4559	3	1.28	…	1.27	1
4560	2	1.28	…	1.25	1

Table 6 shows the raw data of abnormal condition in 3 February. In this work, 440 samples are found in abnormal condition. As an example, for sample 439, the parameter rejected belongs to the height of insulator wire.

Table 6: Abnormal raw data of 3 February

Sample no	Number of scratches	Height of insulator wire	…	Height of excess plastic header	Level of tinning
1	5	1.26	…	1.26	1
2	6	1.26	…	1.26	1
…	…	…	…	…	…
439	2	1.34	…	1.27	1
440	1	1.28	…	1.25	1

Figure 5 illustrates the graph of MD normal and abnormal. The normal MD indicates the yellow graph while the black graph indicates the abnormal MD. Based on the result, the threshold normal MD (0.399768-2.07049) and the abnormal threshold MD (1.363206-7.9982). The SNR gain shows the value 0.3386. It means in positive gain.

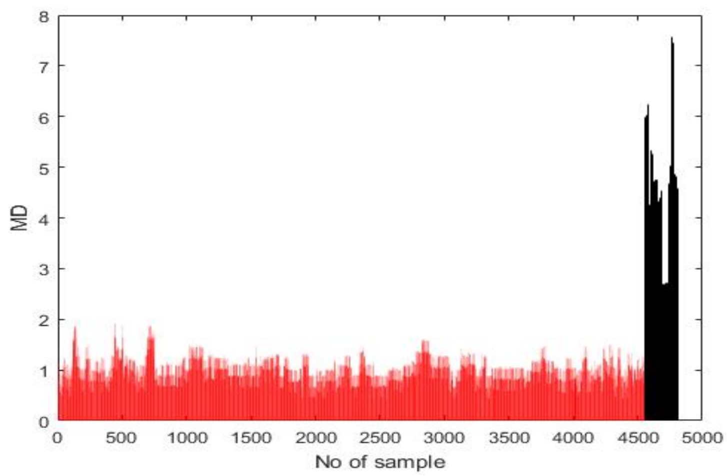

Figure 5: Normal and abnormal MD of 3 February

Table 7 summarizes the raw data of normal condition of 20 December. In this work, 4096 samples are found in normal condition for all parameters that meet requirement of normal limit in production.

Table 7: Normal raw data of 20 December

Sample no	Number of scratches	Height of insulator wire	…	Height of excess plastic header	Level of tinning
1	2	1.24	…	1.28	1
2	1	1.27	…	1.27	1
…	…	…	…	…	…
4095	2	1.26	…	1.27	1
4096	2	1.29	…	1.25	1

Table 8 summarizes the raw data of abnormal condition of 20 December. In this work, 904 samples are found in abnormal condition for all parameters. As an example, for sample number 904, the parameter of rejected belongs to the level of tinning.

Table 8: Abnormal raw data of 20 December

Sample no	Number of scratches	Height of insulator wire	…	Height of excess plastic header	Level of tinning
1	1	1.28	…	1.28	1
2	1	1.28	…	1.28	1
…	…	…	…	…	…
903	2	1.26	…	1.24	1
904	3	1.24	…	1.28	2

Figure 6 illustrates the graph of MD normal and abnormal. The normal MD indicates the yellow graph while the black graph indicates the abnormal MD. Based on the result, the threshold normal MD (0.386806-2.077525) and the abnormal threshold MD (1.335044-6.782965). The SNR gain shows the value 0.3667. It means in positive gain.

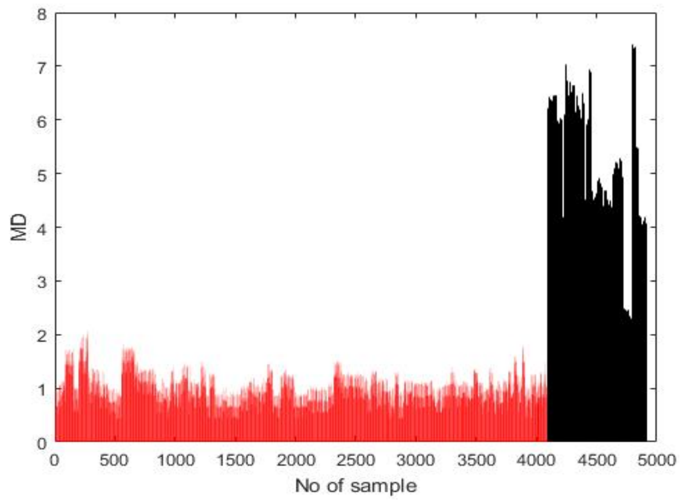

Figure 6: Normal and abnormal MD of 20 December

Based on these selected results, there are overlapped MD thresholds between normal and abnormal. This happened because sample in the abnormal data has few number of parameters complied with abnormal condition. It means if the sample has all the 10 parameters complied with abnormal condition obviously, overlapping will not happen. However, the center of normal and abnormal MD threshold in January are 1.232166 and 4.059005 obviously, both groups are not identical. Similarly, the center of normal and abnormal MD threshold in February are 1.235109 and 4.680703 respectively which is not identical and result in March also supported the justification with 1.225757 and 4.595976 for the normal and abnormal MD threshold respectively. Therefore, MTS is successfully distinguished between the normal and abnormal group through the center of MD threshold.

In this work, there are 10 parameters that considered to reject the magnetic component. The parameters for rejected components are number of scratches, height of insulator wire, condition of stripping, number of epoxy spot on winding coil, condition of marking, distance of winding gap, type of coating damage, height of excess plastic header, level of tinning, and number of epoxy at header corner. In this work, only 8 parameters are considered except the level of tinning and number of epoxy at header corner. These two parameters are eliminated because of standard zero deviation. It means the value of normal limit for all samples have same value, so in the standard deviation, the value will show the '0' value. Table 9 summarizes the selected parameter (√) and reduced parameter (×) for 12 months.

Table 9: Selected and reduction parameter for 12 months

Month	Parameter							
	Number of scratches	Height of insulator wire	Condition of stripping	Number of epoxy spot on winding coil	Condition of marking	Distance of winding gap	Type of coating damage	Height of excess plastic header
January	√	√	√	√	√	√	√	×
February	√	√	√	√	√	√	√	×
March	√	√	√	×	√	√	√	×
April	√	√	√	√	√	√	√	×
May	√	√	√	√	√	√	√	×
June	√	√	√	√	√	√	√	×
July	√	√	√	√	×	√	√	×
August	√	√	√	√	×	√	√	×
September	√	√	√	√	√	√	√	×
October	√	√	√	√	√	√	√	×
November	×	√	√	√	√	√	√	×
December	√	√	√	√	√	√	√	×

Based on Table 9, for January, February, April, May, June, September, October, and December, the reduced parameter is the height of excess plastic header. The reduced parameters of the number spot on winding coil and height of excess plastic header belongs for March. Besides, for July and August, the parameters reduced are condition of marking and height of excess plastic header while for November, the reduced parameters belong to the number of scratches and height of excess plastic header. SNR is a scale to measure the performance of quality. The higher the value of SNR, the better of product quality. Table 10 summarizes the SNR gain for 12 months.

Table 10: SNR gain

Month	SNR Gain
January	0.3298
February	0.3386
March	0.8796
April	0.1430
May	0.3423
June	0.3623
July	0.4925
August	0.7434
September	0.3224
October	0.1608
November	0.5847
December	0.3667

Based on the result, a group of March, July, August, and November approximately have higher SNR gain than a group of January, February, April, May, June, September, October, and December. The main reason is these 4 months have 2 significant parameters which unaffected the operation while the others are similar with 1 significant parameter.

IV. CONCLUSION

This work successfully applied MTS on magnetic component at E&E industry. The positive gain shows the quality of product still in good condition such as the value of SNR gain for January with 0.3298, February with 0.3386 and March with 0.8796. This indicated that without considering the insignificant parameter, the system still can perform better. This work also suggested height of excess plastic header as one of variables in VMI should be removed since the variable does not contribute to the system as shown in 2018. Meanwhile, there are two parameters reduced in March (Number of epoxy spot on winding coil and height of excess plastic header), July and August (Condition of marking and height of excess plastic header) and November (Number of scratches and height of excess plastic header). This concluded that MTS is a practical method for classification and optimization in the industry.

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