Optimization of Process Conditions for Hard Disk Drive Assembly for Defect Reduction

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***Abstract*—A spoiler installed in a hard disk drive can reduce the airflow velocity that causes vibration at an actuator arm and its head. In the case study, a hard disk drive manufacturer identified the defect of a loosely tightened spoiler in the hard disk drive by the spoiler installation machine. This occurred as a result of incorrect screw spacing (also called 'the screwdriver encoder'). There was no study that specifically specified or created a suitable relationship model between the screwdriver encoder and associated parameters for the installation of a spoiler. Factors affecting the screw spacing were determined using multiple regression analysis, and a mathematical model of the significant factors of the screwdriver encoder was built. Data were collected from the spoiler installation machine and its software. Four factors were identified with the potential to impact the screwdriver encoder as (1) vacuum level for picking up the screw, (2) time spent in tightening the screw, (3) bit angle, and (4) screw torque. The ANOVA results pointed out that the screw torque within the range of experimental values did not affect the screw spacing, and a quadratic regression model was the most appropriate under various statistical criteria. This research demonstrated that a sophisticated regression model, i.e., a cubic model, is not always a good choice for an agent. In addition, the optimal values for the spoiler installation machine were determined. The faults decreased by 0.0096% from 0.055% each month. For choosing the relationship model of additional workpiece screw tightening variables, this research phase can be utilized as a guideline.**

***Keywords*—spoiler, hard disk drive, linear regression, polynomial regression, analysis of variance**

I. Introduction

Thailand is a large production base of Hard Disk Drives (HDDs) as an industry that adds value to the country with high competition in both price and quality. Many researchers have examined ways to reduce HDD production cost, while increasing productivity and maintaining product quality. The case study company in Thailand was an industrial factory producing hard disk storage devices, with the main components consisting of slider fabrication, head gimbal assembly, head stack assembly and hard disk drives.

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The case study company has developed its production line as an automated assembly process to increase the ability to meet customer needs and demand in terms of cost, quality, and speed of delivery. Various factors are used in the machine production process including machine design and efficiency of raw material usage. Incorrect variable settings may cause some parts to become defective, as either unable to work or resulting in reduced performance. Therefore, the production process must be strictly controlled to prevent the manufacture of defective products that cause customer dissatisfaction.

The research problem statement considered the spoiler installation machine that was used to secure the spoiler in the Hard Disk Drives (HDDs). For some spoilers, the screw assembly was not tightened sufficiently. This research analyzed the factors affecting the screwdriver encoder values and created an equation to show the relationship of each factor that affected the screwdriver encoder using polynomial regression. Finally, the appropriate factor level was identified by the fitted model and confirmed by conducting experiments.

II. Literature Review

A hard disk drive is a computer device used for both internal and external data storage. Daim *et al.* [1] noted that the number of hard disk drive patents is continually increasing.

A. Literature on the Use of Spoilers and Bypass Channels

Inside an HDD, metal disks or disk platters coated with a magnetic substance are stacked on top of each other as layers, depending on the data capacity. A disk platter is designed to rotate at high revolutions to increase data transmission speed and storage capacity. However, in such a situation, high airflow speed leads to vibration of the actuator arm and the disk platter, resulting in erroneous data transmission. Various research papers have identified the advantages of using a spoiler as an HDD component to reduce airflow speed and the negative impact this causes around the actuator arm [2].

Hirono *et al.* [3] studied how the length and thickness of different sizes of spoiler affected power consumption of the platter spindle motor. As length and thickness

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increased, power consumption of the platter spindle motor also increased, resulting in reduced airflow and vibration of the suspension slider head. Kankaew *et al.* [4] modeled and simulated the airflow within a 3.5-inch hard disk drive by studying the influence of spoiler length on airflow velocity. Their simulation results confirmed that increasing the spoiler length reduced the average airflow speed.

Ikegawa *et al.* [5] studied the working of hard disk drives with and without the use of spoilers, including the use of the bypass way. Their experimental design simulated the airflow in three different ways as Type 1 non-use of the bypass and the spoiler, Type 2 use of the bypass without the spoiler, and Type 3 use of the bypass and the spoiler. The bypass compartment deflected the air stream outwards inside the hard disk drives, and back into the area around the actuator arm. As a result, the spoiler reduced airflow velocity and vibration at the actuator arm by 30%.

Ikegawa *et al.* [6] simulated an experiment to compare airflow distribution and pressure exerted on the suspension slider head between the disk platter in each layer under the presence and absence of the spoiler. Results determined that peak pressure was reduced when a spoiler was present.

Ikegawa *et al.* [6] investigated the phenomenon of polygonal airflow structure at each pressure peak, while Kubotera [7] studied and confirmed the phenomenon of polygonal airflow structure which occurred as triangular, rectangular, pentagonal, and hexagonal under different pressure frequencies.

The literature was summarized and compared in Table I.

TABLE I. LITERATURE ON THE USE OF SPOILERS AND BYPASS CHANNELS

Author	Year	Description and aim	Method
Gupta [2].	2007	The advantages of using a spoiler	literature review
Hirono *et al.* [3]	2004	The effect of the length and thickness of various sizes of spoilers on the platter spindle motor's power consumption	computer Simulation by NAGARE 3D
Kankaew *et al.* [4]	2015	The effect of spoiler length on airflow velocity	computer Simulation by ANSYS Workbench
Ikegawa *et al.* [5]	2006	The effect of spoiler-and-bypass existence on airflow velocity	fluid simulation based on the large eddy simulation (LES) and particle image velocimetry (PIV)
Ikegawa *et al.* [6]	2011	The effect of the suspension slider head between each layer's disk platters under the presence and absence of the spoiler on the polygonal airflow patterns	fluid simulation and pressure measurement based on The large eddy simulation (LES) and particle image velocimetry (PIV)
Kubotera [7]	2012	The existence of rotating polygonal flow patterns inside the actual HDD	computational fluid dynamics (CFD) and experimental flow visualization.

B. Literature on Adding Helium Gas

Aruga *et al.* [8] confirmed that a hard disk drive spinning at a higher speed caused higher vibration. This effect was reduced by adding helium gas to the hard disk drive. More importantly, the positioning error of the suspension slider head was greatly reduced when helium gas was added.

Kil *et al.* [9] expanded the research of Aruga *et al.* [8] by analyzing and comparing airflow properties with and without helium gas addition. They measured the average air speed and turbulence intensity using a computer simulation that considered the disk platter radius, i.e., inner position and outer position. Aruga *et al.* [8] focused on the actuator arm and suspension slider head, while Kil *et al.* [9] focused on the mid–plane measurement between the two disk platters by adding a 1.8-millimeter elevation from the center plane. The advantages of helium gas filling in hard disk drives were promoted by Aruga *et al.* [8] and Kil *et al.* [9]. Furthermore, Bouchard, Talke [10] and Aruga *et al*. [11] studied how helium gas filling in HDDs reduced windage loss. Helium has the second lowest weight after hydrogen gas, and helium gas filling resulted in reduced windage pressure and windage loss since the dynamic viscosity of helium gas is greater than that of air [12].

C. Literature on Setting Systems for Manufacturing Machines

Suriyasuphapong and Rojanarowan [13] studied how the machine setting reduced defective elements of the flexural disk platter using the six sigma technique based on the fractional factorial design method. A second–order polynomial regression was also created to show the relationship between deflection and related variables, including the determination of suitable values for the relevant factors.

Li *et al.* [14] proposed a method to determine the optimal tooth face angle and pole–arc to pole–pitch ratio of the magnet by means of response surface methodology to reduce the cogging torque in the brushless DC spindle motor of the HDDs. Cogging torque occurred in the area between the permanent magnets of the rotor and winding in the slotted stator, resulting in vibration, noise, and inconsistent rotation speed [15].

In the past, the actuator arm worked with the stepping motor to turn the arm of the reader to the desired position to read or write data. The controller served to translate commands from the computer. The stepping motor was later replaced with a faster and more accurate Voice Coil Motor (VCM) [16]. The VCM allowed detailed movement of the mechanical arm using the principle of electromagnetic induction [17].

Machine learning has been used to improve the manufacture of HDDs so that no waste is produced. Holimchayachotikul and Laosiritaworn [18] presented a model following the Taguchi method to optimize the cleaning process parameter at the actuator arm with ultrasonic sound waves, using support vector regression to train the system, while Simongyi and Chongstitvatana [19] studied and compared machine learning methods to detect and distinguish malfunctions of the voice coil motor assembly in HDDs.

Hard disk drives are designed for reliability and long service life because breakdowns cause profound impacts on business operations. There is high competition to produce new models. Accelerated life test procedures are carried out in a short time. Tang *et al.* [20] and Ye *et al.* [21] developed a method for estimating reliability by injecting particles into the HDDs, while Suriyasuphapong and Rojanarowan [13], Li *et al.* [14], and Holimchayachotikul and Laositritaworn [17] focused on setting machine parameters for hard disk drive assembly or function. Here, the installation parameters of the spoiler machine were considered.

The literature review showed that spoilers were one of the most important components of HDDs for main two reasons: reducing the speed of air hitting the disk read/write head and providing anti–vibration. Installation of the spoiler with screws had to succeed. Very few studies have focused on the problem of installing spoilers. Hence, the installation parameters of the spoiler machine were considered in this current research. Optimal parameters were recorded and controlled.

D. Literature on Polynomial Regression

Polynomial regression is one method for modeling curvature in the relationship between a response variable and one or more independent variables by extending the simple linear regression model to include the second or higher order.

In general, there are the following criteria for selecting a suitable model of multiple regression equations [22–24]:

1. The coefficient of multiple determination (R^2) is a statistical indicator of how well a regression model describes a set of data. This metric measures the proportion of the overall sum of squares to the regression sum of squares.

2. The adjusted coefficient of determination (R^2(adj)) is the adjustment for the coefficient of determination. It should be noted that adding an independent variable to a regression model causes the coefficient of multiple determination to increase. The ratio of the regression mean squares to the total mean squares can be used to describe the adjusted coefficient of determination.

3. The Prediction Error Sum of Squares (PRESS) statistic is the sum of the squares of the prediction residuals for those observations that are not used to estimate the model by themselves. To understand the predictive power of a model, PRESS is a decent indicator of the anticipated variance.

4. The predicted coefficient of determination (R^2(pred)) is obtained from the analogous expression 1–[PRESS/SST].

5. The standard error of regression (S) is the square root of the error mean square that is an unbiased estimator of error term variance in the multiple regression models. The mean square for error is obtained by dividing the residual sum of squares by the residual degrees of freedom. This statistic indicates that the smaller it is the better, that is, the more precise will be the predictions.

In addition, there are also criteria that are used in the selection of forecasting techniques: the mean squared error (MSerror) and the Mean Absolute Deviation (MAD) [25–27]. The Mean Absolute Deviation (MAD) can be converted to the forecast error percentage, i.e., the Mean Absolute Percentage Error (MAPE), which is another indicator commonly used measurement precision.

The literature review showed that spoilers were one of the most important components of HDDs for main two reasons: reducing the speed of air hitting the disk read/write head and providing anti–vibration. Installation of the spoiler with screws had to succeed. Very few studies have focused on the problem of installing spoilers. There was no study that explicitly stated or constructed an appropriate connection model between the screwdriver encoder and associated factors for the installation of a spoiler in a hard disk under multiple regression analysis in the thorough literature review, according to in Table I. Hence, the installation parameters of the spoiler machine were considered in this current research. Optimal parameters were recorded and controlled.

III. Materials and Methods

The case study company operated a semi–automatic assembly line of V–type products, with 32 workstations divided into three groups as:

Group 1: Assembly of the disk platter and its functional test

Group 2: Assembly of the other parts

Group 3: Assembly of the hard disk drive cover

In Group 2, this research considered the spoiler installation machine that placed and tightened the screw to secure the hard disc drive. The spoiler operated as a V–type product component to reduce airflow speed inside the hard disk drive.

A Pareto chart showing the number of machine malfunction times and problem type was presented as Fig. 1. The Pareto chart indicated that malfunction of the spoiler installation machine during the process of screw tightening was the most urgent problem for consideration. It was noted that, there were 0.055% faults per month. During the screwdriving process, the machine part of the robot arm did not fully tighten the screw. The screw position was above the specified level, as shown in Fig. 2.

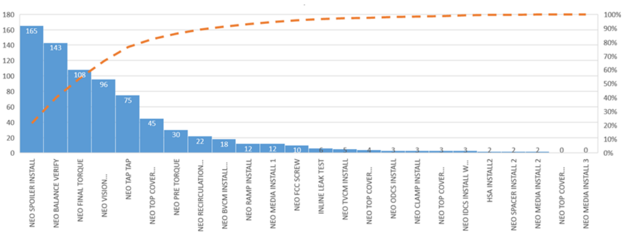

Figure 1. Pareto chart showing problem type and malfunction incidences.

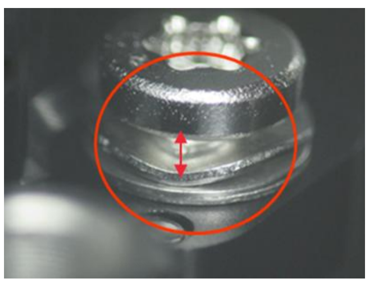

Figure 2. Screwdriving failure (the screw was above the specified level).

The research procedure was shown in Fig. 3. Significant factors related to the screwdriver encoder were determined by polynomial regression analysis.

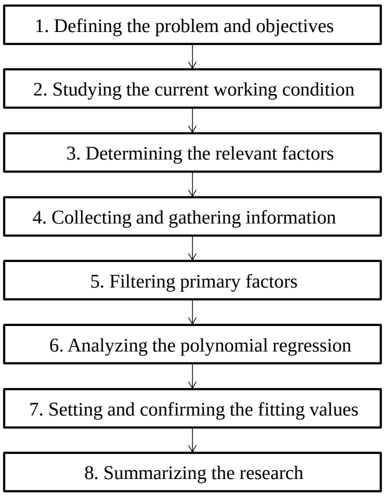

Figure 3. Research procedure.

IV. Result

A. *Determination of the Relevant Factors and Parameters*

The dependent variable or response variable was the screwdriver encoder as the feedback device value used to detect the distance or position of the screw.

The values of the screwdriver encoder are read from the encoder device, which is a sensor for measuring distance and measuring speed based on the principle of measuring the distance from the rotation itself. If the rotation distance around itself is large, the screw spacing will be reduced.

The standard value was in the range of 1 ± 0.55 mm. However, the company was willing to extend the range value to 0.45–0.65 mm to increase the quality of spoiler fixing.

It was noted that the case study firm employed screws spaced more apart than what is typical for items on the market, because it was a brand–new product that emphasized employing automated manufacturing lines. Screw spacing values close to zero were not permitted, though, as they risked damaging the thread and causing an unsuccessful seizure.

The independent variables (or related factors) and their levels were as follows:

(1) Screw torque from 1.48 lbs to 1.50 lbs, denoted by X_1;

(2) Rotation angle of the bit head used by the screwdriver, without a specified range of values, denoted by X_2;

(3) Time spent in tightening the screw at less than 4,000 milliseconds (ms), denoted by X_3;

(4) Vacuum level for picking up the screw between 8.6 and 9.7 MPa (MPa), denoted by X_4;

(5) Screwdriver Z–axis position value of the robot arm with a value of 240.93 mm;

(6) Kicker encoder to keep the spoiler in the specified position before tightening by the screwdriver with a value of 214.359 mm;

(7) X–axis position of the robot arm with a value of 65.89 mm.

Four variables were identified as (1) screw torque, (2) bit rotation angle, (3) time spent in tightening the screw, and (4) vacuum level for picking up the screw. Variables 5 through 7 had constant values and the effects of these factors were not studied.

B. *Data Collection*

All spoiler installation machine data were collected from Log File and JSON File. The files were converted to a spreadsheet to analyze the root cause of machine malfunction in the screwdriving process. Fifty hard disk drives were randomly collected every day for a period of 10 days. Hence, data were collected from 500 discs with some examples shown in Table II.

TABLE II. Examples of Variable Data Used in the Screwdriving Process

Product Code	Torque (lb)	Angle (rpm)	Time (ms)	Vacuum (MPa)	Screwdriver Encoder
WX31D89A0C11	1.488	4114	2979	9.15	0.954
WX31D89A0ACP	1.493	4132.6	2982	9.237	0.971
WX31D89A0C11	1.488	4114	2979	9.15	0.954
WX31D89A0ACP	1.493	4132.6	2982	9.237	0.971
WX31D89A0C11	1.488	4114	2979	9.15	0.954
WX31D89A0C11	1.488	4114	2979	9.15	0.954
WX31D89A0CUH	1.495	4107.7	2983	8.962	0.76
WX31D89A0A95	1.493	3968.2	2942	8.875	0.692
WX31D89A0F4J	1.493	3996.4	2950	9.05	0.701
WX31D89A0ACP	1.493	4132.6	2982	9.237	0.971
WX31D89A0A5D	1.493	4197.9	2997	9.188	1.01
WX31D89A0C11	1.488	4114	2979	9.15	0.954
WX21D690L4HZ	1.494	4228.1	3000	8.787	0.829
WX21D690L13D	1.500	4086.5	2963	9.025	0.666

C. *Primary Factor Filtering by Correlation Analysis*

The correlation analysis was used to test whether or not only one factor affected the response variable. The other independent factors or variables were ignored. The four independent variables, i.e. screw torque (X_1), bit angle (X_2), time spent in tightening the screw (X_3), and vacuum level for picking up the screw (X_4) were analyzed to determine introductory relationships between the independent and dependent variables as shown in Table III.

Results showed that three factors significantly affected the screwdriver encoder as (1) bit angle, (2) amount of time spent in tightening the screw, and (3) vacuum level for picking up the screw. The screw torque was not related to the screwdriver encoder because the P-value was equal to 0.705, which was greater than 0.05, and the pearson correlation was equal to −0.017,

The interaction between the screw torque and other independent variables might affect the screwdriver encoder. Therefore, the screw torque (X_1) was considered in further analysis.

TABLE III. PEARSON CORRELATION AND P-VALUE

Variable	**Screw torque**	**Bit angle**	**Time**	**Vacuum level**
screwdriver encoder.	−0.017 0.705	0.531 0.000	0.913 0.000	0.214 0.000

Cell Contents: Pearson correlation P-Value

D. Polynomial Regression Analysis

The basics of machine learning refer to linear regression and polynomial regression.

The relationship between the independent variables and the dependent variable might not be explained by the linear model, as shown in Table IV. The four independent variables might be related to the tightening encoder as a second or third-degree polynomial model.

TABLE IV. RESULTS OF FITTED REGRESSION LINE

Independent variable	**P-value**		
	Linear model	**Quadratic model**	**Cubic model**
Screw torque (X_1)	0.705	0.744	0.366
Bit angle (X_2)	**0.000***	**0.000***	0.431
Time spent in tightening the screw (X_3)	**0.000***	0.323	**0.000***
Vacuum level for picking up the screw (X_4)	**0.000***	**0.005***	**0.035***

Note: *significance

Potential regression models in this research were divided into two groups as torque-factor-based and non-torque-factor-based regression models.

In the first group, torque-factor-based regression models were linear regression (Models 1–2), quadratic regression (Models 3–4), and cubic regression (Model 5). The interactions between torque variable and others were examined in this group. In the second group, non-torque-factor-based regression models (Models 6–9) were extended from linear regression and quadratic regression in the first group to form other potential best fit models, giving a total of nine models as:

Model 1: Torque-factor-based simple linear regression

Model 2: Torque-factor-based linear regression with two interactions

Model 3: Torque-factor-based quadratic regression with two interactions

Model 4: Torque-factor-based quadratic regression without interactions

Model 5: Torque-factor-based cubic regression

Model 6: Non-torque-factor-based simple linear regression

Model 7: Non-torque-factor-based quadratic regression

Model 8: Non-torque-factor-based cubic regression originated from Table IV

Model 9: Non-torque-factor-based quadratic model without angle-square and time-square terms

The results of multiple regression analyze for all nine models were shown in Table V.

TABLE V. MULTIPLE REGRESSION ANALYSIS FOR ALL TEN MODELS

Index	**Mathematical model**	**R^2**	**R^2(adj)**	**R^2(pred)**	**PRESS**	**S**	**MAPE**	**MSerror**
1.	Torque-factor-based simple linear regression ScrEnc = −2.67 − 1.26 Torque + 0.000126 Angle + 0.001495 Time + 0.0319 Vacuum	84.04%	83.91%	83.72%	1.82390	0.0608517	0.064908	0.004169
2.	Torque-factor-based linear regression with two interactions ScrEnc = −69 + 45.8 Torque − 0.0193 Angle + 0.0142 Time + 11.7 Vacuum + 0.0128 Torque×Angle − 0.0101 Torque×Time − 7.71 Torque×Vacuum + 0.000000 Angle×Time − 0.000093 Angle×Vacuum + 0.000077 Time×Vacuum	84.15%	83.82%	83.44%	1.85606	0.0610248	6.022834	20.58
3.	Torque-factor-based quadratic regression with two interactions ScrEnc = 867 − 1146 Torque − 0.0181 Angle + 0.0037 Time + 4.5 Vacuum + 382 Torque^2 + 0.000001 Angle^2 + 0.000002 Time^2 + 0.1736 Vacuum^2 + 0.0111 Torque×Angle − 0.0022 Torque×Time − 4.12 Torque×Vacuum- 0.000001 Angle×Time + 0.000021 Angle×Vacuum - 0.000524 Time×Vacuum	84.70%	84.25%	83.78%	1.81808	0.0602063	13.88	108.93
4.	Torque-factor-based quadratic regression without interactions ScrEnc = 922 − 1206 Torque − 0.00320 Angle − 0.00205 Time − 2.67 Vacuum + 403 Torque^2 + 0.000000 Angle^2 + 0.000001 Time^2 + 0.1497 Vacuum^2	84.47%	81.21%	83.85%	1.80982	0.0602809	4.487466	11.39
5.	Torque-factor-based cubic regression (ไม่มีตัวไหน sig เลย) ScrEnc = 949 - 1186 Torque − 0.057 Angle + 0.0422 Time − 7.4 Vacuum + 396-Torque^2 + 0.000013 Angle^2 − 0.000013 Time^2 + 0.68 Vacuum^2 − 0.000000 Angle^3 + 0.000000 Time^3 − 0.020 Vacuum^3	84.48%	84.13%	83.65%	1.83202	0.0604380	42.48	1035.89
6.	Non-torque-factor-based simple linear regression ScrEnc = −4.554 + 0.000126 Angle + 0.001495 Time + 0.0322 Vacuum	84.00%	83.90%	83.77%	1.81829	0.0608603	0.048275	0.003674
7.	Non-torque-factor-based quadratic regression ScrEnc = 20.80−0.00325 Angle−0.00187 Time−2.87 Vacuum + 0.000000 Angle^2 + 0.000001 Time^2 + 0.1609 Vacuum^2	84.40%	84.21%	83.97%	1.79621	0.0602805	3.829209	8.329808
8.	Non-torque-factor-based cubic regression ScrEnc = −13 − 0.00362 Angle + 0.0495 Time - 9.6 Vacuum + 0.000000 Angle^2 −0.000016 Time^2 + 0.91 Vacuum^2 + 0.000000 Time^3 − 0.028 Vacuum^3	84.41%	84.15%	83.87 %	1.80729	0.0603849	77.12	3407.63
9.	Non-torque-factor-based quadratic model without angle-square and time-square terms ScrEnc = 9.13 + 0.000127 Angle + 0.001488 Time − 3.00 Vacuum + 0.1684 Vacuum^2	84.18%	84.05%	83.91 %	1.80304	0.0605829	0.047328	0.003667

In Table V, all models had good values for the coefficient of determination (R^2) that were greater than 80%, with nearby values of $R^2_{(adj)}$ and R^2(pred). Model 9 with the lowest Mean Absolute Percentage Error (MAPE) of 0.0473288 and Mean Squared Error (MSerror) of 0.003667 was chosen to represent the data for the screwdriving process of the spoiler installation machine. Model 9 displayed the relationship between variables as follows:

$$\text{Screwdriver encoder} = 9.13+0.000127\ \text{Angle}+0.001488\ \text{Time} - 3.00\ \text{Vacuum} + 0.1684\ \text{Vacuum}^2 \quad (1)$$

It was noted that Model 9 was based on Model 7, where the angle-square and time-square terms had no effect on the screwdriver encoder. Thus, only the vacuum-square term was considered to determine model suitability.

The analysis result of Model 9 was shown in Table VI.

TABLE VI. RESULT OF REGRESSION ANALYSIS OF MODEL 9

Source	DF	Adj SS	Adj MS	F-Value	p-Value
Regression	4	9.4335	2.35837	642.56	0.000
Angle	1	0.0691	0.06908	18.82	0.000
Time	1	5.9367	5.93669	1617.50	0.000
Vacuum	1	0.0195	0.01955	5.33	0.021
Vacuum^2	1	0.0200	0.01997	5.44	0.020
Error	483	1.7727	0.00367		
Total	487	11.2062			
Model Summary:					
S	**R-sq**	**R-sq(adj)**	**R-sq(pred)**		
0.0605829	84.18%	84.05%	83.91%		
Coefficients:					
Term	**Coef**	**SE Coef**	**T-Value**	**p-Value**	**VIF**
Constant	9.13	5.87	1.56	0.120	
Angle	0.000127	0.000029	4.34	0.000	1.35
Time	0.001488	0.000037	40.22	0.000	1.38
Vacuum	-3.00	1.30	-2.31	0.021	5042.61
Vacuum^2	0.1684	0.0722	2.33	0.020	5045.14

E. Analysis of Optimal Levels

In the case study company, the desired value of the screwdriver encoder was between 0.45 and 0.65 mm to prevent defects. However, the condition before improvement had a screwdriver encoder value that exceeded the stated range.

For Model 9, optimal levels analyzed by Minitab Software were displayed in Table VII 5. Bit angle (X_2) was 3957 rpm, time spent in tightening the screw (X_3) was 2938 milliseconds, and vacuum level for picking up the screw (X_4) was 9.23535 MPa. When these factor values were entered in Model 9, the screwdriver encoder was equal to 0.613 mm.

The eight experiment units were collected to confirm the desired screwdriver encoder by setting the spoiler installation machine according to the aforementioned values. The screwdriver encoder values were 0.634, 0.629, 0.616, 0.631, 0.613, 0.617, 0.626, and 0.620, which were equal or close to the desired screwdriver encoder.

The final defects dropped by 0.0096% each month from 0.055%, or an 82.42% decline, overall. This is considered the result of the multiple regression analysis improvement.

TABLE VII. ANALYSIS OF OPTIMAL LEVELS BASED ON MODEL 9

Response	Goal	Lower	Target	Upper	Weight	Importance
Screwdriver Encoder	Target	0.45	0.55	0.65	1	1
Variable Ranges						
Variable	**Values**					
Angle	(3957, 4381)					
Time	(2938, 3401)					
Vacuum	(8.6, 9.525)					
Solutions						
Solution	**Angle**	**Time**	**Vacuum**	**Screwdriver Encoder Fit**	**Composite Desirability**	
1	3957	2938	9.23535	0.612923	0.370773	
2	3957	2938	9.52078	0.617931	0.320688	
3	3957	2938	8.61181	0.636688	0.133123	
4	3957	2956.26	9.48327	0.644315	0.056846	

V. CONCLUSION AND DISCUSSION

Waste production is one of the losses and is considered as a barrier to increasing productivity. All organizations must have an effective operating system to prevent waste and increase productivity, including cost reduction. This research studied one of the hard disk drive manufacturing companies in Thailand. After exploring the quality issues, a Pareto chart was used to prioritize the problem by its occurrence frequency. One of the most importunate problems created an amount of waste, whereby the spoiler installation machine did not correctly tighten the screw to secure spoiler parts in the HDD.

The purpose of this research was to identify the root cause of the spoiler installation machine malfunction in the screwdriving process. Linear regression and polynomial regression analyses were used to study the relationship between the independent and dependent variables.

The spoiler installation machine did not fix the spoiler correctly in the HDD and the screw was not tight. The variance was analyzed to filter the preliminary factors of the four independent variables, i.e. screw torque, bit angle, time spent in tightening the screw, and vacuum level for picking up the screw, along with creating an equation to describe the relationship between the various variables and their specifications.

The following key conclusions were drawn:

(1) Screw torque in the range 1.48 to 1.50 pounds had no relationship with the screwdriver encoder and was suitable for spoiler installation.

(2) Time spent in tightening the screw had a significant effect on the screwdriver encoder values that was greater than the bit angle and vacuum level because it had the highest F-Value.

(3) Model 9 as quadratic regression without X_{22} and X_{32} was determined as the optimal mathematical model, with the best Mean Absolute Percentage Error (MAPE) and Mean Squared Error (MSerror), decision coefficient

(R^2), R^2(adj) and R^2(pred). It was noted that Model 6, representing simple linear regression was also a possible representative because the criteria values were similar to Model 9.

Industrial plants should have a clear policy in place that focuses on adjusting machine settings to fit. Hence, there will be no defects or fewer defects. The equations obtained from the multiple regression analysis can be applied to perform computer self-learning methods such as machine learning, to detect abnormalities in machine operation and prevent waste.

The results of this research were limited to the product. There are other factors that are not considered, such as the properties of the material used to mount the spoiler and the size of the mounting screws. The study's findings were restricted to the item. Other elements, such the characteristics of the fastening material for the spoiler and the size of the mounting screws, were not taken into account. It is anticipated that the findings of this study will serve as a benchmark for future studies to estimate the importance of variables and formulate equations appropriate for different HDD models.

Conflict of Interest

All authors declare that they have no conflicts of interest.

Author Contributions

All authors contributed to the study conception and design. Kittiwat Sirikasemsuk written the first draft of the manuscript; Kittiwat Sirikasemsuk and Kanogkan Leerojanaprapa commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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