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Parametric Analysis in the Electronic Sensor Frequency Adjustment Process

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***Abstract*—**The use of electronic sensors in the electronics industry has become increasingly popular over the past few years, and it has become a high competition product. The frequency adjustment process is regarded as one of the most important process in the electronic sensor manufacturing process. Due to inaccuracies in the frequency adjustment process, up to 80% waste can be caused due to rework processes; therefore, this study aims to provide a preliminary understanding of the role of parameters used in the frequency adjustment process, and also make suggestions in order to further improve performance. Four parameters are considered in this study: air pressure, dispensing time, vacuum force, and the distance between the needle tip and the product. A full factorial design for experiment 2^k was considered to determine those parameters that significantly affect the accuracy of the frequency adjustment process, where a deviation in the frequency after adjustment and the target frequency is expected to be 0 kHz. The experiment was conducted on two levels, using two replications and with five center-points added. In total, 37 experiments were carried out. The results reveal that air pressure and dispensing time significantly affect the frequency adjustment process. The mathematical relationship between these two parameters was formulated, and the optimal parameters for air pressure and dispensing time were found to be 0.45 MPa and 458 ms, respectively. The optimal parameters were examined by carrying out a confirmation experiment in which an average deviation of 0.082 kHz was achieved.

***Keywords*—**Design of Experiment, Electronic Sensor, Frequency Adjustment, Parametric Analysis

I. Introduction

THE electronics industry has continued to expand at an increasing rate due to rapid technological developments, with high levels of competition developing among companies in the sector. In order to maintain business performance, organizations need to change and constantly develop new products so as to meet customer demands in terms of quality, price, and delivery.

Some electronics products, such as amplifiers, loudspeakers, and electronic sensors, employ principles that involve frequency. These products function by converting electrical power into mechanical power, so as to create a vibration in the form of a frequency operating on different phases, or distribute electrical power into a coil to produce ultrasonic frequency induction. These principles are used for various communication devices, varying by product specification and due to customer requirements.

Electronic sensors generate ultrasonic frequencies which are transmitted to detecting objects. These sensors can vary, through the use of simple methods such as the different frequency adjustment of similar types of material in order to generate a different range of frequencies, and thus are able to serve the full range of customer requirements. The adjustment of frequency in the electronic sensor manufacturing process can be carried out in several ways, one of which is to use polymer adhesive to bind the sensor components and reduce the vibration rate of the product, thus resulting in a reduction in the product's frequency range. Frequency reduction can also be conducted on different levels, depending upon the weight of the adhesive used with the product.

The case study company manufactures several models of electronic sensor, each of which is produced in different quantities. Model A has the highest quantity produced. As a result, there is an urgent need to conduct a study and analysis to determine improvements in the manufacturing process of Model A. Within the production process of Model A, the adhesive dispensing process for frequency adjustment is not yet suitable. From measuring the product's frequency after first adjustment, only 20% meet the criteria; the remaining 80% still require rework - for the second and third adjustments. In addition, those products that require more than three adjustments become defects which, in turn, cause higher labor and raw materials costs, as well as a reduction in product quality. Thus, the development of a more suitable adhesive dispensing process is required in order to minimize the risk of losses occurring.

This research; therefore, was conducted in order to identify those frequency adjustment factors that generate a frequency, after first adjustment, that is as close as possible to the target frequency. As a result, a model was developed of the relationship between the frequency adjustment factors significantly affecting the difference between the adjusted frequency and the target frequency of 40.1 kHz, with the ultimate aim being to eliminate any rework - leading to lower production costs, plus higher levels of competitiveness and higher profitability for the company.

II. Design Of Experiment In The Electronics Manufacturing Processes

Based on previous research, Design of Experiment (DOE) and Factorial Experimental Design methods are widely employed to facilitate production process developments and improvements across several industries. In the electronics

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industry, DOE is employed to determine a suitable value for each step in a process and reduce defect rates [1]-[5]. When conducting research, Factorial Experimental Design is commonly applied to identify relevant factors prior to determination of a suitable value for each step in the process. This method can help to reduce experiment times and the quantities of raw materials and other resources used.

For instance, [1] applied DOE using a full factorial design to identify the optimum setting for the color-changing parameters in the alumina substrate sheet manufacturing process, these parameters being belt speed, blower force, temperature, substrate camber, and finally the number of parts in a magazine. This full factorial study was conducted with two replications in order to study the relationship between five factors and the responses. After refining the model, a desirability function was used to find the optimum condition, this being 80 microns of substrate camber and a maximum level for the other factors. This was then efficiently employed to reduce the percentage of cracks in the product from 2.11% to 1.44%, and as a result, company costs were cut by 111,110 Thai baht per month.In addition, [2] conducted a study to find those parameters affecting the glass transition temperature experienced during a casting process, in order to minimize losses in the process. The three parameters found were the mixing ratio of the resin, the curing temperature, and the curing time. The experiment was carried out by applying a full factorial design method using 2^k methodology. The screening experiment results found that the three mentioned parameters were statistically significant to a 95% confidence level. After that, a response optimizer was used to determine those factor levels required to produce the ideal glass transition temperature, these being a mix ratio of hardener and resin of 1.1: 1, a curing temperature of 150°C and a curing time of 110 minutes.Similarly, [3] conducted a study into the most suitable conditions required for electronic circuit board soldering using a wave soldering process, in order to reduce defects. Six factors were initially identified after which a factor identification process was then conducted through use of a Fractional Factorial Design (2^{6-1}), finding that the conveyor angle, as well as the chip wave and electric voltage for lambda wave significantly contributed to product defects. The factors obtained were then used again for an experimental design and analysis using the Response Surface Methodology based on the Box-Behnken Design. The results of the experiment showed that those conditions producing the minimum number of product defects were a chip wave of 33.5 volts, a conveyor angle of 6.5 degrees and an electric voltage for lambda wave of 40 volts. The research results show that the total number of defects was reduced from 41,240 to 9,020, a reduction of 76.75%.

From a review of previous studies, it can therefore be seen that the use of DOE can determine a suitable set of values for processes requiring re-development; thus attention should be focused on those relevant factors identified, their levels and the experiment control conditions, so as to obtain the most accurate experimental results.

III. Fluid Dispensing

The fluid dispensing process is widely used in the electronics component manufacturing industry, through the application of production processes such as coating (dispensing a substance in order to coat the product surface), dispensing adhesives in order to bind products to a circuit board, dispensing solder to connect the circuits, and dispensing adhesives to adjust frequencies.

There are various types of fluid dispenser, some of which are widely used, such as the Time-Pressure Dispenser, the Auger Pump Dispenser, the Piston Valve Dispenser, and the Jetting Dispenser [6]. Among these, the Time-Pressure Dispenser is the most widely used because it is low cost, is simple to operate and maintain, flexible and has many applications [7].

In order to effectively control the fluid dispensing process using a Time-Pressure Dispenser, many researchers have studied the most appropriate way to control the dispenser’s functions. In doing so, most research studies have involved the creation of a theoretical process model and mathematical equations related to fluid dynamics [7] - [9]. In addition, [10] conducted a study using a full factorial experimental design to develop a model to control the use of a microchip coating substance for the semiconductor manufacturing industry. The factors and the levels used in this experiment were an air pressure set at 4 levels, a motor speed set at 6 levels, and a distance from the needle tip to the product (height) set at 4 levels. A study into the two responses, these being weight and thickness of the coating substance, was then carried out, and predictive equations created using a regression model. The results show that those factors significantly affecting the weight of the coating substance were the air pressure and the height, and the interaction between the air pressure and the height, while those factors significantly affecting the thickness of the coating substance were the air pressure and the height.

IV. Research Methodology And Results

As previously described, this study aims to determine those factors affecting frequency adjustments within the electronic sensor manufacturing process by using the DOE technique. The study research began with an examination of the machine operating instructions and the work standards set for the processes, so as to identify those factors likely to affect frequency adjustments for the electronic sensor products. Throughout the experiments in this study, the same tools and equipment as well as workers were employed, and the raw materials were produced from the same lot, in order to minimize the impact of uncontrollable factors. The research steps followed plus the results are as follows:

A. Electronic Sensor Production Process and Frequency Adjustments

The production process for electronic sensors is shown in Fig.1.

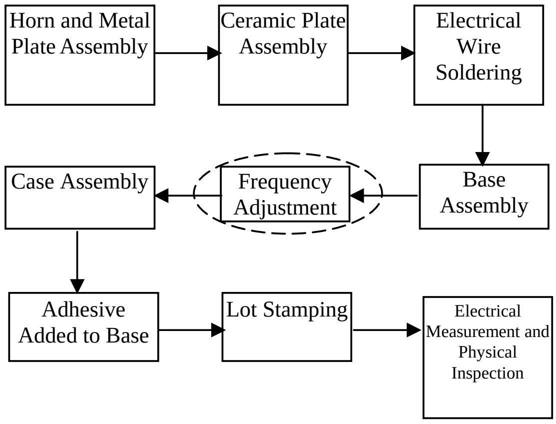

Fig. 1 Electronic sensor production process

During the frequency adjustment process, workers measure the frequency of the products; thereafter grouping them so as to carry out adjustments by adding adhesive to reduce the amount of vibration. In addition, the value of the adhesive dispenser is set differently for each group of products. From the frequency adjustment; however, the target frequency cannot be obtained with just a first attempt, so a second and third adjustment is required in order to reduce the frequency from the starting point and obtain the required value (40.1 kHz).

B. Factors and Design of the Experiment

Based on previous studies and the equipment operating instructions, the researchers selected a total of four factors to use in the study, these being: air pressure, adhesive dispensing time, vacuum force, and distance from the needle tip to the product. The response obtained was the difference in frequency between the adjusted value and the target value. As the sensor products are initially set at a frequency higher than the target value, an adjustment is often required in order to reduce the difference to as close to 0 as possible. For this research, the experiments were carried out using electronic sensors (Model A) with a frequency range of 42.4 to 42.7 kHz, and a full factorial design study was conducted using four factors and with two levels. The factors and levels used are shown in Table I.

TABLE I
FACTORS AND LEVELS

Symbol	Factors	Levels	
		Low (-1)	High (+1)
A	Air Pressure (MPa)	0.45	0.55
B	Dispensing Time (ms)	450	550
C	Vacuum Force (kPa)	-0.8	0
D	Distance between the Needle and the Product (mm)	1	3

The researchers determined the level of each factor by examining the machine operating instructions, assessing the limitations of the study company and carrying out a preliminary experiment so as to prevent damage to products, tools and equipment.

Factor A - air pressure: If the air pressure is lower than 0.45 MPa, it is not enough to dispense the adhesive. However, the air pressure used for dispensing adhesive at the study company is set at 0.55 MPa or below.

Factor B: dispensing time: The preliminary experiment showed that if the time taken to drop adhesive on to the product is less than 450 ms, not enough will be added. Also, if the time taken to drop adhesive on to the product is more than 550 ms, too much will be added and it will overflow, causing a defect.

Factor C – vacuum force: Vacuum force is used in the case of adhesive with a low viscosity. If a vacuum force is not applied, the adhesive will drip from the tip of the needle while it is not being used. However, if a vacuum force is applied, it will create tension in the adhesive, and preventing the low viscosity adhesive from flowing from the tip of the needle. The maximum vacuum force that can be applied is 0 kPa, and the minimum is -10 kPa. However, as the minimum force has an impact on the rubber adhesive dispensing head, in that the head stays afloat within the adhesive tube causing an error in the amount of adhesive applied, a preliminary study was carried out to determine the minimum force that could be applied without causing the adhesive dispensing head to stay afloat during the experiments. The force obtained from this preliminary study (-0.8 kPa) was then set as the minimum vacuum force for the experiments.

Factor D – the distance from the tip of the needle to the product: The minimum distance which can be employed when applying adhesive is 1.0 mm, for if the distance is less than 1.0 mm, the tip will be stained with adhesive and the amount applied will not meet requirements. The maximum distance which can be employed is 3.0 mm, for if the distance greater than 3.0 mm, the adhesive will overflow, causing a defect.

For this research, randomization principle was applied with two replications, and an additional five experiments at the center point were conducted, to provide protection against curvature from second-order effects, as well as to allow an independent estimate of error to be obtained [11]. A total of 37 experiments were then carried out.

C. The Initial Frequency of Electronic Sensors and Preliminary Hypothesis Testing

As this research set the initial electronic sensor frequency range at 42.4 to 42.7 kHz, with the mean value of 42.55, a one-sample hypothesis using a Z-test to a significance level of 95% was conducted in order to validate this fundamental assumption. The results show that the P-value, at 0.065, was higher than the level of $\alpha = 0.05$; thus, it can be concluded that the null hypothesis was satisfied, in which the initial frequency of the experimented products was close to the mean value of 42.55.

D. Checking for Model Adequacy

After conducting the experiments and measuring the adjusted frequency of the products after the first adjustment, the frequency obtained was used to determine the difference between the adjusted frequency and the target frequency of 40.1 kHz, with a difference of 0 kHz being optimal. The differences obtained from this calculation were then used for further analysis.

The fundamental DOE assumptions were checked, these being that the errors should be normally and independently distributed with a mean of zero and a constant but unknown variance. Residual analysis was then carried out to check the model's adequacy.

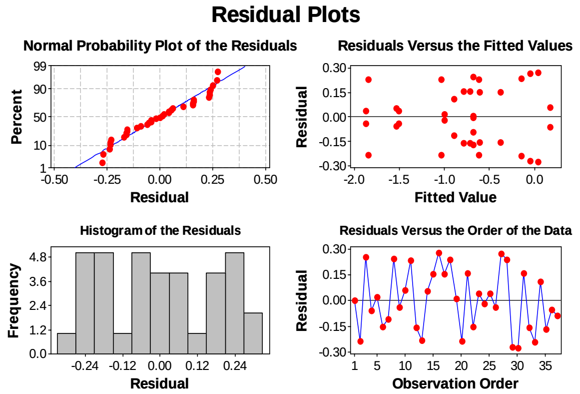

Fig. 2 Residual plots

From Fig.2, it can be seen that the normal probability for the residuals appeared satisfactory. In addition, the plots for the residuals in terms of the time sequence for each response show that the assumption of independence or a constant variance was satisfied. The plots for the residuals versus the fitted values do not reveal any obvious pattern; therefore, all the assumptions were satisfied. It can thus be concluded that the data were adequate to be utilized in an analysis to determine those factors affecting the difference between the adjusted frequency and the target frequency of the sensor products, as undertaken during the next step.

E. Analysis of the Results

After data adequacy testing, the researcher conducted an analysis in accordance with the factorial experimental design 2^k steps [11], as detailed below.

1) Estimate Factor Effects

The first step in the statistical evaluation of the experiment design [11] was an analysis to estimate the main effects and the interaction between those factors affecting the difference between the adjusted and target frequencies. The results are shown in Table II.

TABLE II
THE P-VALUE FOR EACH FACTOR AFFECTING THE ADJUSTED FREQUENCY AND THE TARGET FREQUENCY

Term	Effect	Coefficient	T-value	P-value
Constant		-0.7972	-18.89	0.000
A	-0.9569	-0.4784	-11.34	**0.000**
B	-0.7344	-0.3672	-8.70	**0.000**
C	-0.1594	-0.0797	-1.89	0.074
D	-0.1569	-0.0784	-1.86	0.078
A*B	-0.0944	-0.0472	-1.12	0.277
A*C	0.1131	0.0566	1.34	0.195
A*D	-0.0644	-0.0322	-0.76	0.454
B*C	-0.0244	-0.0122	-0.29	0.776
B*D	-0.0444	-0.0222	-0.53	0.605
C*D	0.1456	0.0728	1.73	0.100
A*B*C	0.0456	0.0228	0.54	0.595
A*B*D	-0.0694	-0.0347	-0.82	0.421
A*C*D	0.0131	0.0066	0.16	0.878
B*C*D	-0.0219	-0.0109	-0.26	0.798
A*B*C*D	-0.1369	-0.0684	-1.62	0.12
Center Points		0.1172	1.02	0.319

S = 0.238689 R-Sq = 91.77% R-Sq(adj) = 85.19%

From Table II, it can be seen that only air pressure (A) and adhesive dispensing time (B) significantly affected the responses, to a confidence level of $\alpha = 0.05$. This result is in line with the results obtained from the Normal Probability Plot of the Standardized Effects, as shown in Fig.3.

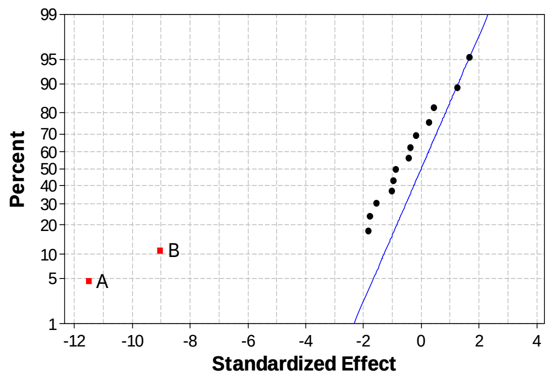

Fig. 3 Normal Probability Plot of the Standardized Effects

In addition, from Table II, it can be seen that R-Sq, representing the accuracy of the analysis, is 91.77%, and that R-Sq(adj) - representing the accuracy of only those factors affecting the difference between the adjusted and target frequencies, these being air pressure and adhesive dispensing time - is 85.19%. These results mean that the accuracy of the analysis was satisfied.

2) Initial Model Formulation

An analysis of the impact of the factors on the responses, including the main effects and the interaction between the factors, was conducted - as shown in TABLE II. The coefficients from the experiments were then used to form equations regarding the relationship between the factors and the responses. The formulation of (1) is as follows:

$$\hat{Y} = -0.7972-0.4784X_A-0.3672X_B-0.0797X_C \ldots - 0.0684X_{ABCD} \quad (1)$$

Where $\hat{Y}$ refers to a predictive value for the response, and X_N refers to a coded value for the factor N.

3) Statistical Testing

An Analysis of Variance (ANOVA) was used to test the significance of the impact of the factors, and the results are shown in Table III.

From Table III it can be seen that those factors significantly affecting the differences in frequency were the main effects only. The interaction between factors had no impact on the responses, as the P-value was higher than $\alpha = 0.05$. In addition, the ANOVA from the experiments, conducted at the center points to test whether or not the responses would produce a quadratic curve, showed that the P-value of the curvature was higher than the level of $\alpha = 0.05$. It can thus be concluded that the model obtained was a first-order model only.

4) Model Refinement

The insignificant main factors and the interactions were excluded from the model. Only the significant factors were then used to develop a relationship equation using regression analysis, to a confidence level of $\alpha = 0.05$. The results of the regression analysis are shown in TABLE IV.

In Table IV, R-Sq is 85.0% and R-Sq(adj) is 84.1%, both of which are higher than 80%. As a result, the analysis generated errors to an acceptable level. The formulation of (2) is as follows:

$$\hat{Y} = 7.6708-9.4750X_A - 0.00744X_B \quad (2)$$

Where $\hat{Y}$ refers to a predictive value for the response, and X_N refers to a coded value for the factor N.

TABLE III
ANALYSIS OF VARIANCE FOR THE FULL MODEL

Source	DF	Sum of Squares	Mean Square	F-Value	P-Value
A	1	7.18205	7.18205	117.01	0.000
B	1	4.42531	4.42531	72.1	0.000
C	1	0.18000	0.18000	2.93	0.106
D	1	0.17405	0.17405	2.84	0.112
A*B	1	0.05780	0.05780	0.94	0.346
A*C	1	0.08611	0.08611	1.40	0.254
A*D	1	0.04351	0.04351	0.71	0.412
B*C	1	0.00180	0.00180	0.03	0.866
B*D	1	0.00980	0.00980	0.16	0.695
C*D	1	0.14851	0.14851	2.42	0.139
A*B*C	1	0.01051	0.01051	0.17	0.684
A*B*D	1	0.04961	0.04961	0.81	0.382
A*C*D	1	0.00405	0.00405	0.07	0.801
B*C*D	1	0.00781	0.00781	0.13	0.726
A*B*C*D	1	0.13005	0.13005	2.12	0.165
Error	16	0.98210	0.06138		
Total	31	13.49310			

Source	DF	Sum of Squares	Adjusted Mean Square	F-Value	P-Value
Main Effects	4	11.9614	2.99035	55.29	0.000
2-Way Interactions	6	0.3475	0.05792	1.06	0.412
3-Way Interactions	4	0.0720	0.01800	0.33	0.853
4-Way Interactions	1	0.1301	0.13005	2.40	0.137
Curvature	1	0.0642	0.06423	1.19	0.289
Residual Error	20	1.0817	0.05408		
Pure Error	20	1.0817	0.05408		
Total	36	13.6569			

TABLE IV
REGRESSION ANALYSIS

Predictor	Coefficient	SE Coef.	T-value	P-value
Constant	7.6708	0.6151	12.47	0.000
A	-9.4750	0.8681	-10.92	0.000
B	-0.00744	0.000868	-8.57	0.000

S = 0.245522 R-Sq = 85.0% R-Sq (adj) = 84.1%

5) Determination of Optimum Conditions for the Final Model

In the experiments, the difference between the adjusted and target frequencies was set at 0, and from the working standards, an acceptable difference range was set at a higher and lower level of 0.2 kHz around 0. Each factor optimal value was then analyzed using the Response Optimizer function in a Minitab Program, so as to establish Composite Desirability. The starting point of the air pressure factor was at 0.45 MPa and the adhesive dispensing time 450 ms. As a result, those factors affecting the difference between the adjusted and target frequencies (target at 0, which will generate a desirability level of 1), are an air pressure of 0.45 MPa, and an adhesive dispensing time of 458.097 ms. The vacuum force should be set at 0 kPa, the value currently being used under working conditions, and the distance from the tip of the needle to the product should be set at 1 mm - to facilitate control of the adhesive flow and to prevent the risk of adhesive-stained products caused by a changing adhesive flow direction.

6) Validation of the Optimum Conditions for the Processes

In this final step, after the optimum factors were obtained, an experiment to validate the experimental results was conducted, with ten samples. The ten sample products were first tested the hypothesis that the initial frequency was in the range 42.4 to 42.7 kHz. The results from the experiment showed that the mean of the absolute difference between the adjusted and target frequencies differed from the target frequency by 0.082, which is close to 0. Whereas, the adjusted frequency obtained from the company previous procedure was 40.43 kHz, which is 0.33 kHz different from the target frequency. The two processes above produced different results. Furthermore, while the company previous process procedure still requires a second and third adjustment in order to reach the target; the proposed process derived from this study requires only a single adjustment, resulting in the elimination of any rework in terms of a second and third frequency adjustment.

V. Conclusion And Discussion

The research results show that those factors that significantly affected the difference between the adjusted and target frequencies for the electronic sensor products were air pressure and the adhesive dispensing time, both of which are factors controlled by the fluid dispenser. The results of this research are in line with the previous study carried out in this area. Reference [10] conducted a research study to examine those factors suitable for the control of a fluid dispenser when dispensing a microchip coating substance in the semiconductor manufacturing industry. The study [10] found that those factors significantly affecting the control of the fluid dispenser were air pressure and the distance between the tip of a needle and the product, for which air pressure affected the responses – and this result is in line with our study result. However, distance from the tip of the needle to the product had no effect on the differences between the adjusted and target frequencies found in our study, as the required responses were different. In our research, a study was conducted into the control of adhesive amounts only, while the research conducted by [10] also studied the thickness of the coating substance. Thus, distance from the tip of a dispensing needle to the product in question has an impact on the thickness of the fluid, as does the interaction between air pressure and distance.The results of this research identify those factors which affect the adjusted and target frequencies within a frequency adjustment process, and also the model needed to show a relationship between factors and responses. Thus, these results may be used as a guideline for the improvement of existing models and the development of new models in the production of electronic sensor products.

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