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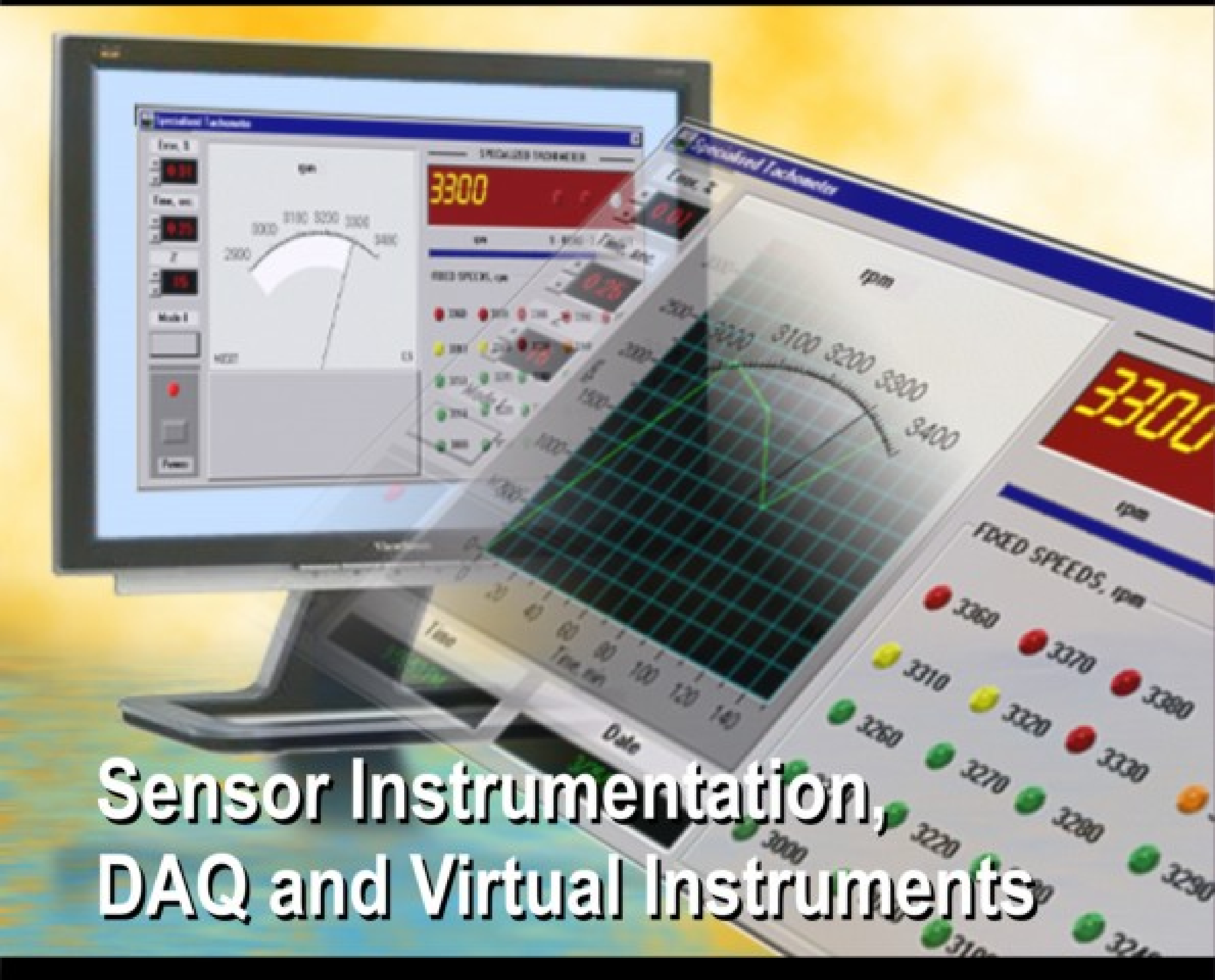

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A Response Surface Methodology Model for Optimizing Electromagnetic Acoustic Transducers' Parameters

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Abstract: Flaw detection is one of the most important problems that pipeline industries are concerned. Conventional ultrasonic method needs coupling medium, and is not more suitable for in-line inspection systems. Electromagnetic acoustic transducers can be used as a good alternative technique in the applications of in-line inspection. However, it is relatively new technique and effectively needs more research. The response resolution is directly related on amplitude of ultrasonic waves. This paper presents signal amplitude model in inspection of steel plate in terms of magnetic current, static magnetic field and thickness of plate using response surface methodology. The established equation shows that the magnetic current was found to be main influencing factor on the signal amplitude. The variance analysis for the polynomial model reveals that the interaction terms and the square terms for static magnetic field except the interaction with magnetic current were statistically insignificant. However, it could be seen that the second-order effect of static magnetic field is significant. After magnetic current, thickness of plate is the most influencing factor on signal amplitude while the impact of static magnetic field is negligible.

Keywords: electromagnetic acoustic transducers, response surface methodology, flaw detection, and inspection

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1. Introduction

Many industries such as gas and petroleum, and aerospace, electric power industries are concerned with pipeline flaw detection problems. In the conventional piezoelectric based ultrasonic methods, minimizing the scattering of the waves needs coupling medium that is mostly oil or water. This limitation restricts UT's application for point-to-point inspection, and it is difficult and expensive to use for in-line inspection [1]. In the electromagnetic acoustic transducers (EMATs), Ultrasonic waves are produced and propagated insight of the wall thickness unlike UT techniques [2]. In the last decade, it has been established many researches in the field of EMAT based techniques. It is found that ultrasonic guided waves have had successes in flaw detection, but it is still needs further study and validation before it can be accepted in pipeline industries. The main advantage of using guided ultrasonic waves is that they can interrogate the entire specimen, including inaccessible portions [3]. The operational efficiency of an EMAT system is dependent on the design of the EMAT and its supporting electronics, the proximity to the sample surface and the specific properties of the material being examined. The signal an EMAT generates is not as strong as those obtained by other means and hence, extra care must be employed in the signal processing and power conditioning circuits when using this approach. However, it is necessary to determine which process conditions will meet specifications related to signal amplitude. Response surface method (RSM) is a practical, economical and relatively easy for use. The aim of the present study is, therefore, to develop signal amplitude model for steel plates in terms of magnetic current, static magnetic field and thickness of plate. By using response surface methodology and 4 levels design of experiment, polynomial model have been developed with %95 confidence level.

2. Design of Experiment

Experimental design is a critically important engineering tool for improving of process. Designed experiments can often be applied in the product design processes. This will produce information concerning which factors are most influential one, and through use of this information the design can be improved.

The global form of the observed response is,

$$y_{ij} = \mu + \tau_i + \varepsilon_{ij} \begin{cases} i=1,2,\ldots,a \\ j=1,2,\ldots,n \end{cases}, \tag{1}$$

where y_{ij} is the (ij)the observation, μ is a parameter common to all factors called the overall mean, τ_i, is a parameter associated with the factor level called the (i)the factor effect, and ε_{ij} is a random error component.

In design of experiment techniques, it is interested to test the equality of the a factor level means.

$$\begin{aligned} &H_0 : \tau_1 = \tau_2 = \ldots = \tau_a = 0 \\ &H_1 : \tau_i \neq 0 \qquad \text{for at least one } i \end{aligned} \tag{2}$$

That is, if the null hypothesis is true, then each observation is made up of the overall mean μ plus a realization of the random error ε_{ij}. The fundamental analysis of variance equation in test procedure for the hypotheses in question (2) is

$$\begin{aligned} &\sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij} - \bar{y}_{..})^2 = \\ &\quad n\sum_{i=1}^{a}(\bar{y}_{i.} - \bar{y}_{..})^2 + \sum_{i=1}^{a}\sum_{j=1}^{n}(y_{ij} - \bar{y}_{i.})^2 \end{aligned} \tag{3}$$

Also, it can be written symbolically as,

$$SS_T = SS_{Factor} + SS_E \,, \tag{4}$$

where, SS_T is the total sum of squares, SS_{Factor} is called the sum of squares due to the Factor, and SS_E is called the sum of squares due to error.

If SS_{Factor} is large, it is due to differences among the means at the different factor levels. Thus, by comparing the magnitude of SS_{Factor} to SS_E it can be seen that how much variability is due to changing factor levels and how much is due to errors. This comparison leads to a statistical test based on *F* distribution for the equality of the factor means using the test static

$$F_0 = \frac{MS_{Factor}}{MS_E} \tag{5}$$

Where, MS_{Factor} and MS_E are the Mean Square Error and Mean Square for Factor levels, respectively. They can be extract by dividing of SS_{Factor} and SS_E to there number of degrees of freedom. If $F_0 \succ F_{\alpha,a-1,a(n-1)}$, we may conclude that the factor-level means are different.

3. Response Surface Model

RSM is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [4].

If all of the variables are assumed to be measurable, the response surface can be expressed as

$$Y = f(x_1, x_2, ..., x_k) \tag{6}$$

The goal is to optimize the response variable '*Y*'. It is assumed that the independent variables are continuous and controllable by the experimenter with negligible error. In an EMAT System the proposed relationship between the signal amplitude and process independent variables can be represented by the following:

$$A = C.B^n.I^m.T^p.\varepsilon \,, \tag{7}$$

where *A* is the signal amplitude in mm, *B, I, T* are the static magnetic field (mT), magnetic current (*A*) and thickness of plate (mm), respectively. *C, n, m*, and *p* are constants and ε are a random error. Equation (7) can be written as a linear form in order to facilitate the determination of constants and parameters.

Here, a polynomial model was developed with experimental data to study the nature of relationship between three parameters and desired response. In this study it has been used about 30 experimental data to conduct an analysis of variance. This data is the same that was available in reference number [5].

4. Development of a Model

EMAT is a complex device consisting of the electromagnet or the permanent magnet being source of the constant magnetic field, the generating coil supplied by an RF current and the detecting coil connected with an RF amplifier. The EMAT system that is used for this study to generate S_0-mode Lamb waves has been come in Fig. 1.

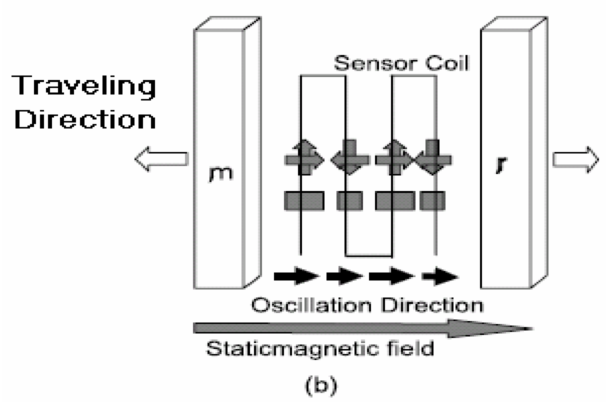


Fig. 1. Driving mechanism by the EMAT to produce Lamb waves. [5].

Lamb waves are guided ultrasonic waves capable of propagating relatively long distances in plates and laminated structures. Lamb wave is selected for this study because of its great sensitivity for thickness of plate and defect sizes.

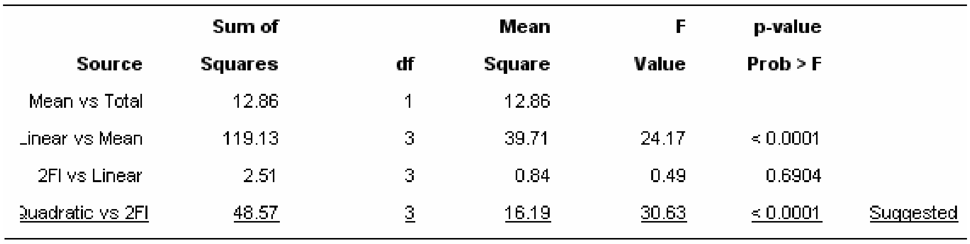
The experimental design was carried out for 0.6, 1.0, 2.0 and 6.0 mm thick steel plates. The sensor coil that was used had a 3mm interval between leadlines. The sequential model sum of squares is used to select the highest order polynomial where additional terms are significant and the model is not aliased. Table 1 shows that quadratic model is the best choice for this experimental design.

5. ANOVA analysis

The analysis of variance (ANOVA) was used to check the adequacy of the quadratic model. However, some errors typically results in this model from measurement error, the effects of variables not included in the experiment, variation due to chance causes in the process, and so on [7]. Table 1 shows the ANOVA table for response surface quadratic model for signal amplitude. The Model *F*-value of 45.24 implies the model is significant.

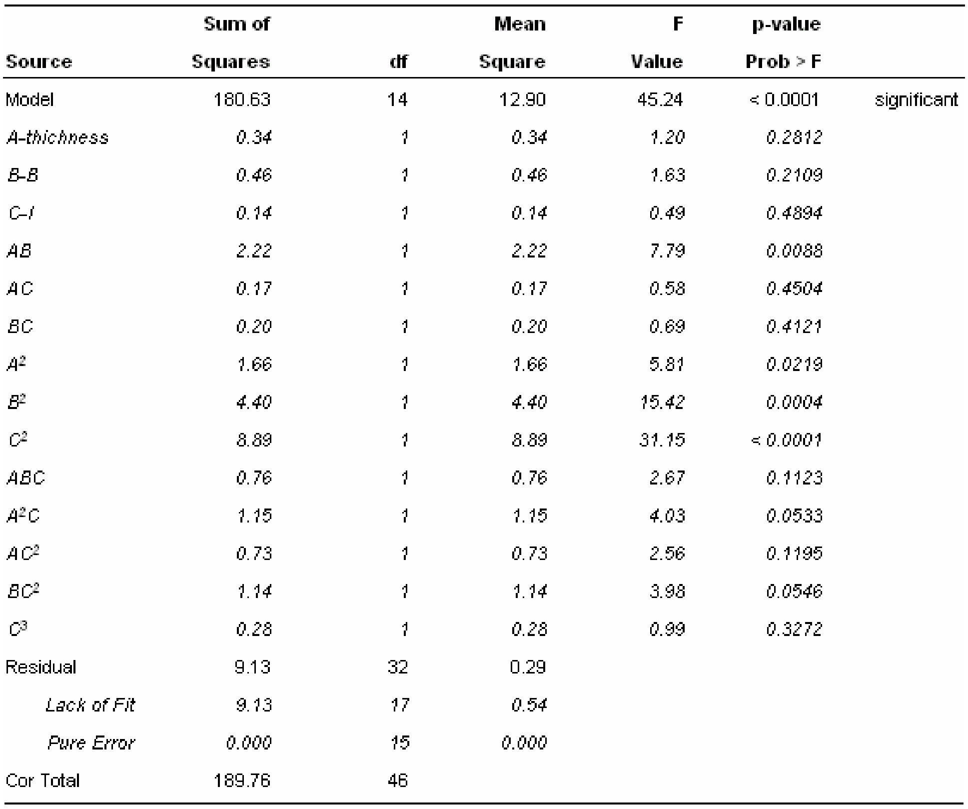
Values of "*Prob* > *F*" less than 0.0500 in Table 2 indicate that the model terms are significant. This is desirable as it indicate that the terms in the model have significant effect on the response.

Table 1: Sequential Model Sum of Squares [Type I].



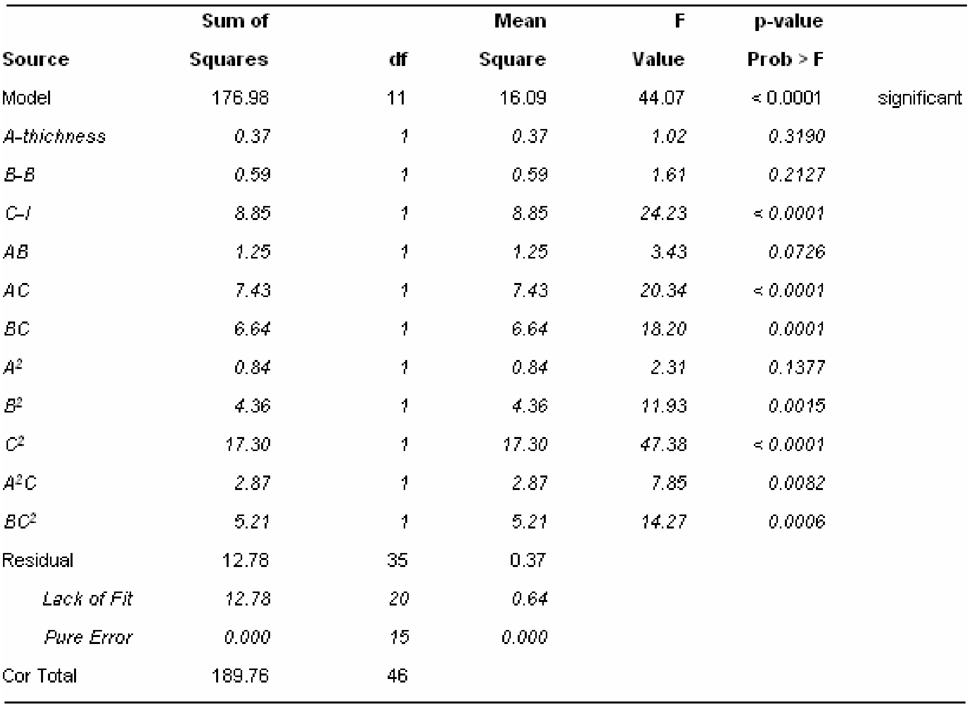
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Mean vs Total	12.86	1	12.86			
Linear vs Mean	119.13	3	39.71	24.17	< 0.0001	
2FI vs Linear	2.51	3	0.84	0.49	0.6904	
Quadratic vs 2FI	48.57	3	16.19	30.63	< 0.0001	Suggested

Table 2. ANOVA for Response Surface Cubic Model (Partial sum of squares-Type III).



Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	180.63	14	12.90	45.24	< 0.0001	significant
A-thichness	*0.34*	*1*	*0.34*	*1.20*	*0.2812*	
B-B	*0.46*	*1*	*0.46*	*1.63*	*0.2109*	
C-I	*0.14*	*1*	*0.14*	*0.49*	*0.4894*	
AB	*2.22*	*1*	*2.22*	*7.79*	*0.0088*	
AC	*0.17*	*1*	*0.17*	*0.58*	*0.4504*	
BC	*0.20*	*1*	*0.20*	*0.69*	*0.4121*	
A^2	*1.66*	*1*	*1.66*	*5.81*	*0.0219*	
B^2	*4.40*	*1*	*4.40*	*15.42*	*0.0004*	
C^2	*8.89*	*1*	*8.89*	*31.15*	*< 0.0001*	
ABC	*0.76*	*1*	*0.76*	*2.67*	*0.1123*	
A^2C	*1.15*	*1*	*1.15*	*4.03*	*0.0533*	
AC^2	*0.73*	*1*	*0.73*	*2.56*	*0.1195*	
BC^2	*1.14*	*1*	*1.14*	*3.98*	*0.0546*	
C^3	*0.28*	*1*	*0.28*	*0.99*	*0.3272*	
Residual	9.13	32	0.29			
Lack of Fit	*9.13*	*17*	*0.54*			
Pure Error	*0.000*	*15*	*0.000*			
Cor Total	189.76	46				

Table 3. Resulting ANOVA Table (partial sum of Squares) for reduced quadratic model (response: Signal amplitude).

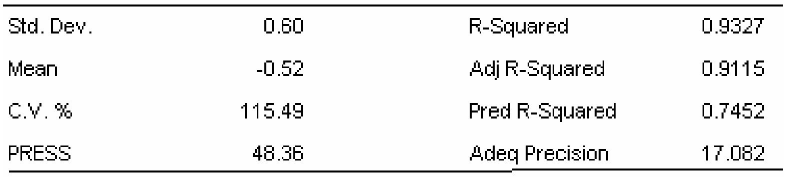


Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	176.98	11	16.09	44.07	< 0.0001	significant
A-thichness	*0.37*	*1*	*0.37*	*1.02*	*0.3190*	
B-B	*0.59*	*1*	*0.59*	*1.61*	*0.2127*	
C-I	*8.85*	*1*	*8.85*	*24.23*	*< 0.0001*	
AB	*1.25*	*1*	*1.25*	*3.43*	*0.0726*	
AC	*7.43*	*1*	*7.43*	*20.34*	*< 0.0001*	
BC	*6.64*	*1*	*6.64*	*18.20*	*0.0001*	
A^2	*0.84*	*1*	*0.84*	*2.31*	*0.1377*	
B^2	*4.36*	*1*	*4.36*	*11.93*	*0.0015*	
C^2	*17.30*	*1*	*17.30*	*47.38*	*< 0.0001*	
A^2C	*2.87*	*1*	*2.87*	*7.85*	*0.0082*	
BC^2	*5.21*	*1*	*5.21*	*14.27*	*0.0006*	
Residual	12.78	35	0.37			
Lack of Fit	*12.78*	*20*	*0.64*			
Pure Error	*0.000*	*15*	*0.000*			
Cor Total	189.76	46				

In this case AB, A^2, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. By selecting the backward elimination procedure to reduce the terms that are not significant, the resulting ANOVA table for reduced quadratic model for surface roughness is shown in Table 3. Results from Table 3 indicate that the model is still significant.

As you can see in Table 4, R-Squared value is high, close to 1, which is desirable. The predicted is in reasonable agreement with the adjusted R-Squared. The adjusted R-Squared value is particularly useful when comparing models with different number of terms. This comparison is however done in the background when model reduction is taking place. Adequate precision compares the range of the predicted values at design points to the average prediction error. Ratios greater than 4 indicate adequate model discrimination. In this particular case the value is well above 4.

Table 4. Model summary Static.



Std. Dev.	0.60	R-Squared	0.9327
Mean	-0.52	Adj R-Squared	0.9115
C.V. %	115.49	Pred R-Squared	0.7452
PRESS	48.36	Adeq Precision	17.082

The BOX COX plot has been used to determine the most appropriate power transform to apply to response data. LOG transform has been selected, based on the best lambda value, which is found at the minimum point of the curve generated by the natural log of the sum of squares of residuals. A constant *k*=0.063 has been added to responses to be sure that they are greater than zero. Figure (2) shows the Box-Cox plot for Power Transforms.

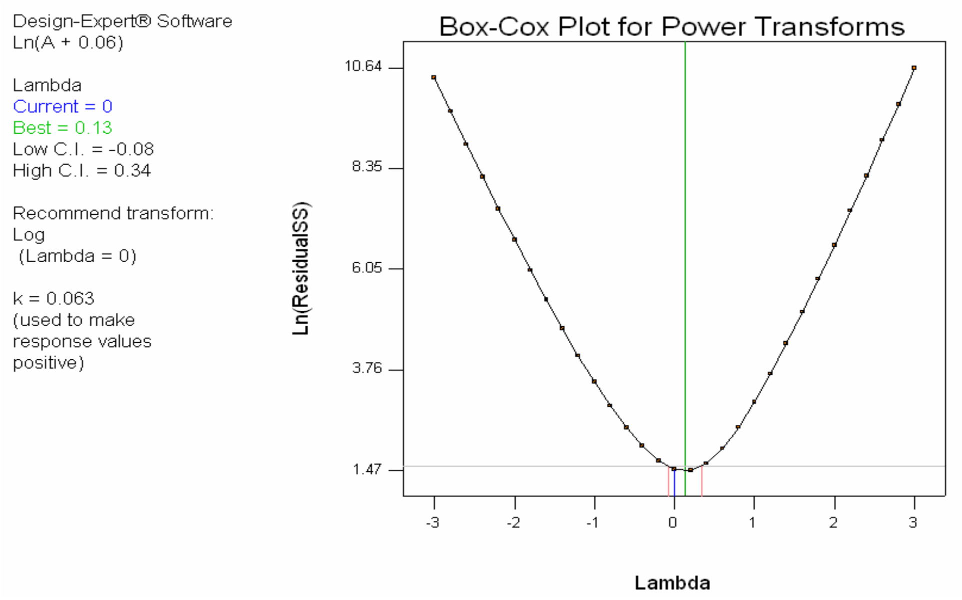


Fig. 2. The Box-Cox plot to determine the most appropriate Power Transform.

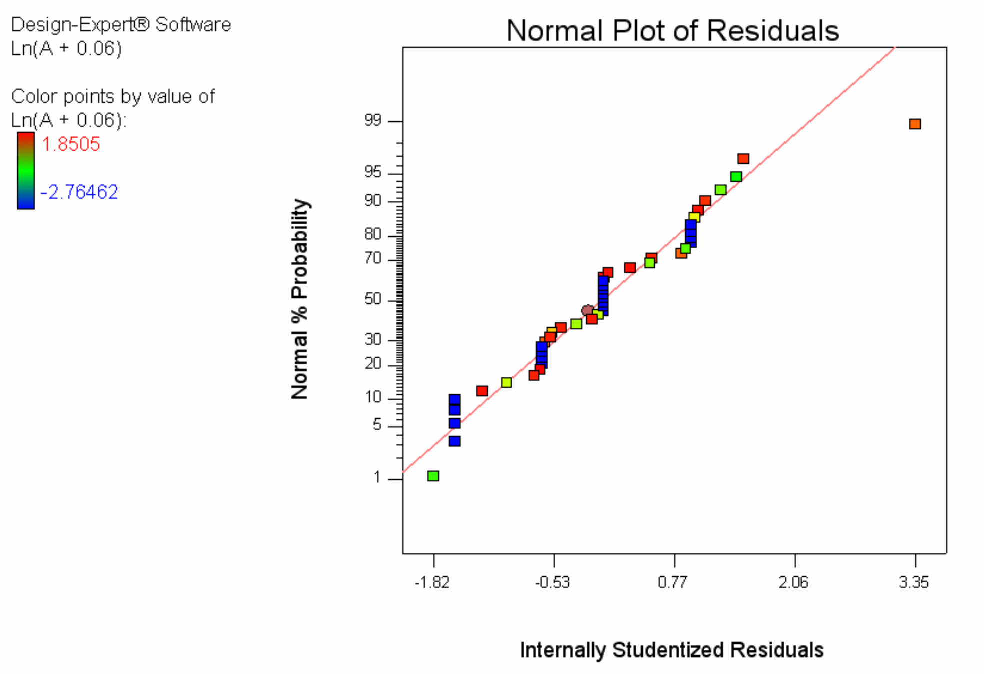


Fig3. Normal probability diagram of the residuals.

Multiple linear regression models for amplitude can be obtained by applying a logarithmic transformation that converts non-linear form into following linear mathematical form

$$\ln A = c_0 + c_1 I + c_2 B + c_3 T + c_4 IB + c_5 IT + c_6 BT + c_7 I^2 B + c_8 IB^2 + c_9 I^2 C + c_{10} IC^2 + c_{11} B^2 C + c_{12} I^3 + c_{13} B^3 + c_{14} C^3 + c_{15} IBC \tag{8}$$

The regression analysis technique using least squares estimation was applied to compute the coefficients of the model for Amplitude (*A*). The following model for a determined are given, respectively

$$\ln(A + 0.063) = -50.80 + 18.47I + 1.74B - 9.73T - 0.28IB + 3.61IT + 0.17BT - 0.015B^{2} - 4.61I^{2} - .29T^{2}I + 0.04BI^{2} \tag{9}$$

Normal probability plot of the residuals for signal amplitude are shown in figures 3. A check on the plot in this figure reveals that the residuals generally fall on the straight line implying that the errors are distributed normally.

6. Conclusions

The following conclusions may be drawn from developed model by the use of RSM for EMATs process conditions. Polynomial model for signal amplitude has been developed using response surface methodology in inspection of steel plate. The established equations clearly show that magnetic current has greater effect on signal amplitude followed by the thickness of the plate. However, static magnetic field has not important effect. The variance analysis for the quadratic model shows that the interaction terms and the square terms inspect of the square term of magnetic current are statistically insignificant.

Two type of force is concerned in an Electromagnetic mechanism of EMAT that is named Lorentz force and magnetostrictve force. Lorenz force can be originated from static magnetic field and dynamic magnetic field. Lorenz force due to dynamic magnetic field is independent of the static magnetic field. The Lorenz force due to static magnetic field is dependent on the static magnetic field. When Magnetic current is increased, the Lorentz force cause of both sources is increased. This is more effective to increase the signal amplitude in compare of using greater static magnetic field.

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References

[1]. Jian. X, S. Dixon, K.T.V. Grattan, R. S. Edvards. A model for pulsed Rayleigh wave and optimal EMAT design, *Sensors and Actuators A* 128, 2006, 296-304.

[2]. Doniavi. A, Eskandarzade. M. A model for Rayleigh wave propagation in the EMAT systems. In Proceedings of International Conference on Energy and Environment (ICEE ‘06), 2006.

[3]. C.valle, M.niethammer, J.Jacobs. Crack characterization using guided circumential waves. *J. Acoustic. Soc. Am*. 110 (30, pt. 1) Sep. 2001.

[4]. D.C. Montgomery. Design and Analysis of Experiments, 4th ed., Wiley, New York, 1997.

[5]. Murayama. R, Makiyama. S, Kodama. M, Y. Taniguchi. Development of an Ultrasonic inspection robot using an electromagnetic acoustic transducer for Lamb wave and SH-plate wave, *Ultrasonics,* 42, 2004, 825-829.

[6]. K. Capova, I. Cap D. Faktorova. Special problems of electromagnetic-acoustic transducer for material non-destructive testing, *International Journal of Applied Electromagnetics and Mechanics*, 15 (2002) 73-77.

[7]. D.C. Montgomery. Introduction to statistical quality control, John Wiley, New York, 1996.

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