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Remaining Useful Life Analysis of an Electrolytic Capacitor Using Statistical Techniques

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Abstract
From toy to aircraft, the use of electronics is prominent. The reusable capability of the electronic component can be decided after predicting the remaining useful lifetime of the electronic component. A multiple regression-based approach is used for predicting the reliability and residual lifetime of electrolytic capacitor under various electrical parameters and environmental conditions. An error of 13.51% is reported, while estimating the residual life using Minitab18.1 software.
Keywords–*reliability, remaining useful lifetime, regression analysis, electrolytic capacitor*

1. Introduction

Speed and cost-effective devices are high in demand, as they are capable to save the money and time of the users. The other side of the developing system is its reliability and lifetime issue. A product which is not reliable, can destruct the entire electronic system within couple of seconds. In many electronic circuits, the components are installed serially. The failure of one component can trigger the failure of entire gadget or electronic device[1]. So, remaining useful lifetime prediction of the component is very necessary, at various electrical parameters and environmental conditions[2].
When the electronic component is launched in the real market, the level of environmental conditions and electrical parameters vary due to other affecting elements. This results in the lifetime variation, as compared to the life claimed by the datasheet. The electrolytic capacitor consists of an anode foil covered by a dielectric layer, a cathode and the electrolyte liquid[3]. Temperature rise decreases the viscosity of dielectric substrate and decrease the equivalent series resistance (ESR). The statistical methods i.e. regression is used to predict the remaining useful lifetime of an electrolytic capacitor using MINITAB 18.1 software[4].

2. Prediction of remaining useful lifetime using analytical method

The analytical method depicts the residual lifetime prediction of electrolytic capacitor using mathematical formula, which is dependent on the ESR values, temperature, voltage, current and the other environmental factors and electrical parameters[5].

2.1 Residual life calculation using analytical method

The life of electrolytic capacitor is estimated by the formula given below:

$$\mathbf{Lp = Lx*2y} \qquad \mathbf{(1)}$$

Where, $y = (Tm-Ta-\Delta T)/10$; $\Delta T = I\hat{}2*ESR/ (B*A)$
Lp = Predicted life of electrolytic capacitor; Lx = Load life of electrolytic capacitor
Tm = Maximum temperature; Ta = Ambient temperature; ΔT = Temperature rise
I = Ripple current; B = Thermal constant of capacitor; A = Surface area of capacitor

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For electrolytic capacitor 224SML050MD4 It reflects, the capacitor will attain maximum lifetime 16771.14 hours, corresponds to the predictors having values i.e. temperature is 80^{o}C, current is 24 milliampere, humidity is 78%Rh, voltage 5.6V and ESR value is 10.1.

3. Statistical Techniques for Prediction of Remaining Useful Lifetime

Statistical methods are describing a collection of data. There are different techniques. Regression and Bayesian techniques are the widely used statistical methods for RUL prediction[6].

3.1 Regression Analysis using Minitab 18.1

The relationship between predictor variable and response is described by regression line. An algebraic representation of regression line is known as the regression equation[7]. The relationship between the independent process parameter variables (temperature, ripple current, humidity, voltage and ESR) and residual life can be represented by the following mathematical model[9]:

$$RL \text{ (Residual life)} = C\,(t^{l}\ r^{m}\ h^{n}\ v^{o}\ e^{q}) \qquad (2)$$

where, RL is the measure of response (residual life), t,r,h,v and e represent the values of the process parameters, C is a model constant and l, m, n, o and q are model parameter[7]. The coefficients for the regression model are determined using Minitab statistical software 18.1.

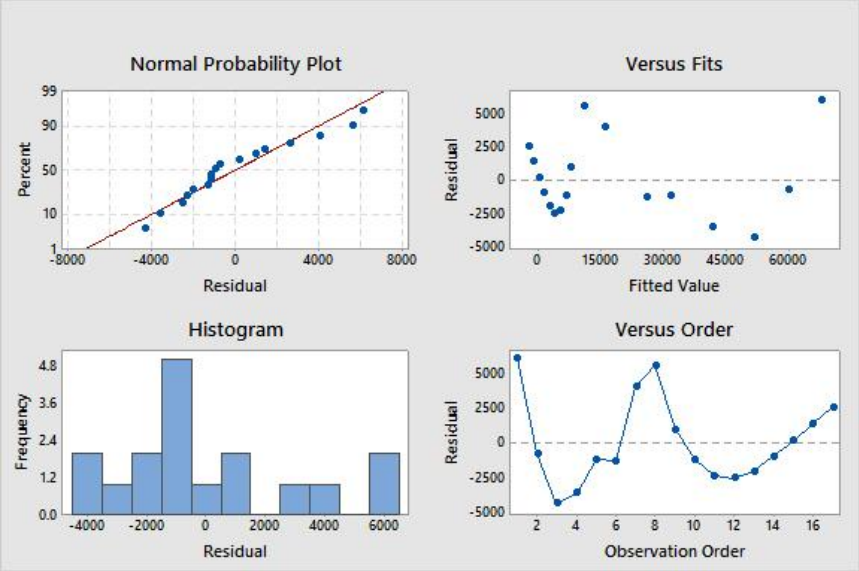

Figure1: Regression output plot using Minitab

The regression equation has been concluded using Minitab 18.1 software. By putting different values of input, the residual life is obtained, which is compared with actual lifetime, to explore the accuracy of the regression model[11].

4. Results and discussion

The electrolytic capacitor is examined over various statistical parameters and values, then a regression model is constructed, which further verifies its accuracy and prediction capability as the following table.

Table 1: Results of regression analysis

Predictor	Coefficient	SE coefficient	T	P

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Constant	-34297.252	14143.140	-2.425	.025
Temperature	2240.528	96.096	23.315	.000
Current	4124.356	1319.581	3.126	.006
Voltage	4515.701	654.529	6.899	.000
Humidity	8579.569	3279.480	2.616	.017
ESR	15975.023	13467.959	1.186	.250
S=810.6		R^2 = 98.1 %	Adjusted R^2 = 96.41 %	

4.1 Lifetime Prediction of Electrolytic Capacitor Using Regression

Using Minitab 18.1 software, Regression equation is obtained, which will predict the values as per regression response[12]. The regression model is given under:

Lifetime= -34297 + 2240.5 Temperature + 4124 Current + 4516 Humidity + 8580 Voltage + 15975 ESR (5)

By inserting the different values (as per Design of Experiment (DOE) data), of predictors i.e. Temperature, Current, Humidity, Voltage and ESR, the value of response i.e. lifetime of capacitor can be predicted[13]. It reflects, the capacitor will attain maximum lifetime 14,768.88 hours, corresponds to the predictors having values i.e. temperature is 80^{o}C, current is 24 milliampere, humidity is 78%Rh, voltage 5.6V and ESR value is 10.1[14].

4.2. Error Analysis of Regression Model

By comparing the calculated failure time or residual lifetime using analytical method with the failure time calculated using regression analysis, the error can be calculated as per following equation (6).

$$Error\ (\%) = \frac{Analytical - Regression}{Analytical\ value} \times 100 \quad (6)$$

So, after putting the residual lifetime values as predicted by analytical and regression, the error in regression analysis comes out to be 13.51%.

5. Conclusion

An electrolytic capacitor is widely used passive component for the applications in toy to satellite. Statistical techniques are used to predict the remaining useful lifetime of an electrolytic capacitor. Minitab18.1 is used to predict the RUL values for various electrical parameters and environmental conditions. The multiple regression is used for 0.22µf electrolytic capacitor is accurate technique having error 13.51%. This predicted technique is useful for the re-use capability of the component or device.

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