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Electrolytic Capacitor Lifetime Prediction in Ground Mobile Applications

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Abstract- Electrolytic capacitors are widely used in several power electronic systems. Their high energy density (J/cm^3) features make them an attractive candidate for smoothing voltage ripple in supply circuitry. However, electrolytic capacitors have the shortest life span of components in power electronic circuits, usually due to their wear-out failure. The main wear-out mechanisms in electrolytic capacitors are the loss of the electrolyte by vapor diffusion trough the seals and the deterioration of the electrolyte.
In this paper, a corrective model for reliability prediction is presented. This model is employed satisfactorily to estimate lifetime duration according to manufacturers' tests. An implementation of this method is proposed, which can be very helpful for predicting the capacitor reliability and alerting plant operators to execute maintenance and/or replacement of the component.

I. Introduction

Industrial applications, such as DC power supplies commonly uses electrolytic capacitors as an integral part of the device. The main functions of the electrolytic capacitors are smoothing voltage ripple and store electric energy. Their large capacitance, large energy density [J/cm^3] and low price make them be the ideal choice to accomplish this objective [1].
Nevertheless, failures in electrolytic capacitors are the main cause of breakdowns in power supplies mainly due to the wear-out [2, 3].
They have the shortest span of life out of all the other components and thus determine the whole system's lifetime. The load life specifications for aluminum electrolytic capacitors used in operating at maximum permitted core temperature are typically 5,000 to 10,000 hours. Solid Aluminum Capacitors with Organic Semiconductor Electrolyte capacitor have a load life of 2,000 hours at 105 °C but estimate of a capacitor's life is approximately 10 times at 20 °C reduction. [4]
The literature states that the main causes of wear-out mechanism in electrolytic capacitors are the loss of the electrolyte by vapor diffusion trough the seals and/or the deterioration of the electrolyte [2,5].
Furthermore, they may have to withstand extreme and harsh temperature which accelerate the electrolyte evaporation process and reduces their life time [5].
However, with the aluminum electrolytic capacitor there is a yield point (time) depending on the dry-up of the electrolytic solution. Considering the Solid Aluminum Capacitors with Organic Semiconductor Electrolyte capacitor, there is not such phenomenon and the tendency for gradual decrease continues semi-permanently [4].
The change in standing almost never differs in the presence of voltage application except for the change of leakage current.
The capacitor's wear-out mechanisms can result both in loss of electrolyte results and fluctuations of its internal equivalent series resistance (ESR) [2, 3].
Reliability data bases uses several methods to predict lifetime [6] but they don't estimate the deterioration status of the electrolytic capacitor; reliability prediction doesn't match the real lifetime related to a particular application. When comparing data-sheets of different electrolytic capacitors manufacturers [4, 7], an inconsistent use of terms like "load life", "useful life", "endurance", "life expectancy", "operational life", and "service life" becomes obvious. In addition to different limits that define the end of the lifetime, some manufacturers even use different standards that leads to a certain amount of test items to be out of the specified range – this makes a comparison of the various lifetime values between suppliers very difficult [8-12]. In this paper, some corrective factors for electrolytic capacitor are take into account in order to estimate the best lifetime prediction matching their deterioration condition. A more detail failure rate evaluation allows to a better definition of maintenance policy and, at the same time, a more accurate definition of the parameters involve in the functional safety assessment [13-19].

II. Reliability Model Of Electrolytic Capacitors

In order to estimate reasonably the failure rate of a capacitor an appropriate model is required. Several reliability data bases have different capacitor models. Equation 1 depicts the reliability model introduced in *MIL HDBK 217* [20] which has been widely accepted.

$$\lambda = \lambda o + \sum_{\pi=1}^{i} (\pi_{iM} C_{iM}) \qquad (1)$$

where C_{iM} , π_{iM} are respectively corrective coefficient and P_i factor of MIL-HDBK 217 Reliability model. By using an updated data base for electronic components is quite immediate to plot λ [hour $^{-1}$] or MTBF [hour] for a generic-application electrolytic capacitor

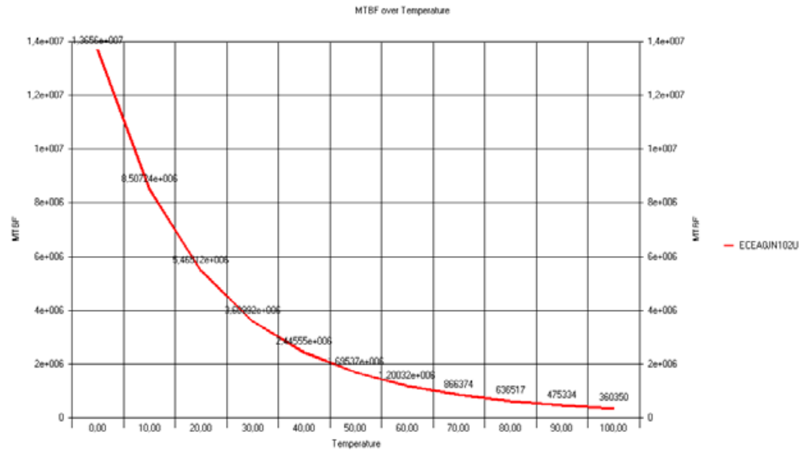

Figure 1. Plot of MTBF vs Temperature for an aluminum electrolytic capacitor – generic application – GM (Ground Mobile) MIL HDBK 217 model

Equation (2) depicts the model introduced in TELCORDIA [21] which has been widely accepted.

$$\lambda = \lambda o + \sum_{\pi=1}^{i} (\pi_{iT} C_{iT}) \qquad (2)$$

where C_{iT} , π_{iT} are respectively corrective coefficient and P_i factor of TELCORDIA Reliability model.
By using an updated data base for electronic components is possible to plot the failure rate λ [hour $^{-1}$] or MTBF [hour] trend of the electrolytic capacitor used in a generic-application.

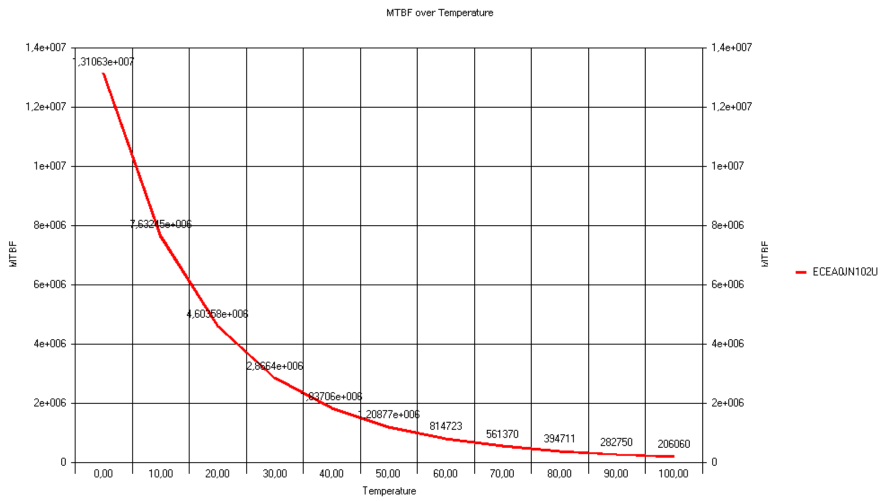

Figure 2. Plot of MTBF vs Temperature for an aluminum electrolytic capacitor – generic application – GM (Ground Mobile) TELCORDIA model.

Due to the difference between MIL and TELCORDIA data bases, the two plots shows significant difference of predicted values of MTBF. The applicability of the models and their results depend on the specific product type and the particular application. Both values are also very different from the predicted failure rate reported in the technical notes of manufacturers.

III. Proposed Corrective Model

It can be stated that the predicted failure rate for electrolytic capacitor is mismatching the deterioration status. Therefore, using the manufacturers' data sheet, power dissipated by the capacitor, the RMS value of the current (*Is*) flowing through the capacitor and the voltage stress applied (*Us*), a best reliability prediction for lifetime (*L*) can be carried out.
Typical electrical and thermal properties of electrolytic capacitors influences the lifetime L and can be modeled by a product of K_i -factor that multiplies the load life L_o (see Eqs. 3 and 4) specified by the manufacturer:

$$L = L_0 \prod K_i \qquad (3)$$

$$L = L_0 \, K_T \, K_I \, K_V \qquad (4)$$

where each parameter is obtained by the following equations:

$$K_T = 2^{\left[\frac{(To-Ta)}{10}\right]} \qquad (5)$$

$$K_I = K_i^{\left[1-\left(\frac{Is}{Ir}\right)^2\right]\frac{(\Delta t)}{10}} \qquad (6)$$

$$K_V = \left(\frac{Us}{Ur}\right)^{-n} \qquad (7)$$

with K_i , Δt , Ir, To, Ur and $-n$ depending on the supplier specification parameters.
The parameter *Ta* represent the operative ambient temperature and *Us* is the voltage stress.
Using the K_i factor descripted above it is possible to obtain:

$$L = L_0 \, 2^{\left[\frac{(To-Ta)}{10}\right]} \; Ki^{\left[1-\left(\frac{Is}{Ir}\right)^2\right]\frac{(\Delta t)}{10}} \; \left(\frac{Us}{Ur}\right)^{-n} \qquad (8)$$

This model is employed satisfactorily to estimate lifetime duration in accord to manufactures' tests [4, 7]. In order to prove the validity of this approach a comparison between the model shown in Equation 8 and the MIL HDBK and TELCORDIA models has been carried out.
The results of this comparison are summarized in Table I. Several types of electrolytic capacitors are taken into account. The hypothesis of such analysis are:

- Operative temperature: 40°C
- Capacitor case temperature: 70°C
- Operating environment: Ground Mobile (GM). This environment is typical of equipment installed on wheeled or tracked vehicles and equipment manually transported; includes tactical missile ground support equipment, mobile communication equipment, tactical fire direction systems, handheld communications equipment, laser designations and range finders. Mobile implies the equipment will encounter vibration. Thus represent the environment that well represent automotive and railway application.

Table I. comparison among the proposed model and MIL-HDBK 217 and TELCORDIA models

Cond.	*Nominal life (h)*	*Rated temperature °C (T_0)*	*Delta T (°C)*	*Capacitor case temperature (T_X) °C*	*Ripple current Ia(A)*	*Nominal ripple current Ir(A)*	*Voltage Ur (V)*	*Calculated life (h)*	*Predicted life (h) Telcordia*	*Predicted life (h) MIL-HDBK217*
C6, C11, C12 (Al)	10000	105	5	70	0,65	1,38	250	148158	421311	529419
C17, C18 (Al)	7000	105	5	70	0,01	0,29	63	111953	389749	484777
C7, C10 (Al)	7000	105	5	70	0,01	0,29	63	111953	389749	484777
C3 (Al)	7000	105	5	70	0,01	0,29	63	111953	334484	691380
C4, C5 (Al)	10000	105	5	70	1,10	1,43	100	130334	389749	529419
C40 (Al)	8000	105	5	70	0,06	0,95	35	127798	334484	484777
C20 (OSCON)	5000	105	20	70	1,80	4,3	20	187819	334484	529419

For each capacitor analyze the worst case is always represented by the proposed corrective model.

II. Conclusions

Aluminum electrolytic capacitors often determine the lifetime of electronic devices. A thorough knowledge of some of the key parameters and aging concepts of these components are necessary to ensure the reliable design of electronic devices with a predictable lifetime. The lifetime of aluminum electrolytic capacitors is largely dependent on the application conditions. Environmental factors include temperature, humidity, atmospheric pressure and vibrations. Electrical factors include operating voltage, ripple current and charge/discharge. A corrective method to determine the best reliability prediction in order to taken in account the deterioration condition of electrolytic capacitors has been presented. The approach can be extend also for other industrial application such as Power Supplies, UPSs and other similar devices.

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