The constitutive materials the capacitors engineering essay

Engineering

20. 2. 2 CapacitorsIntroductionThere are few electronic components which – carrying out the same function – can differ so much from the constitutive materials point of view as the capacitor. Concerning the constitutive materials, the capacitors are built from two electrodes isolated with a dielectric medium, serving to store an electrical charge. The prime objective of any system is that it must meet the basic operational performance. High reliability, good maintainability, electromagnetic compatibility, and other desirable goals are of course important, but they are secondary factors. The struggle between the basic performance requirements and the reliability and maintainability requirements are often reflected in the part selection problems. Choosing the latest types of parts can improve performance and sometimes leads to an increase of the reliability level. Great care is needed to ensure the following: (a) the new part (range) is indeed superior; (b) the new part will become a de facto standard and thereby multi-sourced; (c) the new part is qualifiable to a degree equal to standard parts of roughly similar function. Capacitors may be purchased off-the-shelf as established reliability (ER) devices for most parts. Various screening programs, established on the basis of life-test criteria, are available. As an example, ceramic capacitors may be screened at twice rated voltage for a specified time period, at a maximum rated temperature. Details may be found in [1]. Ceramic capacitors are generally no more reliable than aluminium electrolytic capacitors because aluminium electrolytic self heal. Since high capacitance ceramic capacitors may develop micro-cracks, aluminium electrolytic capacitors are preferred for high capacitance values. For applications operating at high temperatures (> +65°C) the choice should be ceramic

capacitors. Aluminium Electrolytic CapacitorsHalf-dry electrolytic wound capacitors (the most used) are formed from an oxidized aluminium foil (anode and dielectric) and a conducting electrolyte (cathode). A second aluminium foil is utilized as covering cathode layer. They are available with two formed non-polarized foils and they have large loss factor (frequency and temperature dependent), a limited useful life, and are not too reliable (✧ = 10 to 50 FIT; drift, shorts, opens). If their utilization cannot be avoided, it is better to choose the types built with high-quality requirements. In the case of aluminium electrolytic capacitors for high requirements – besides the unavoidable early failures – they have nearly always wear-out failures, too. The beginning of these wear-out failures limits their usability. These capacitors are often the first elements in the system to fail. The failures can be attributed to adverse operating conditions, such as high temperatures, voltage surges and current spikes. A reliability dependence on the size of the case and of the electrolyte quantity was proved: the smaller the capacitor, the shorter the useful life and the higher its failure rate. The operating capacity of these types is limited by the existence of a determined adequate electrolyte quantity. As a consequence of diffusion, aging or decomposition, the active electrolyte quantity of a capacitor system diminishes and leads to a growth of the loss factor (tan ⬮) or to a diminution of the capacity. These modifications are important in the case of fluid electrolytes; for the solid semiconductor electrolytes, the changes are insignificant and – generally – do not lead to capacitor failure. The growth of the leakage current over a certain limit serves as failure criterion for this capacitor type, since tan ⬮ and the capacity have only unimportant variations. Due to the structure and to the operation mode of electrolytic capacitors, the voltage stresses at the nominal value are not taken into account; the solution for accelerated testing is the operation at high temperatures. In the case of operation at temperatures over the guaranteed limit value given by the manufacturer, supplementary electrolyte losses appear. It results that one must remember that the life duration of a capacitor is inversely proportional to the specific loading: $q = U . C / V$ (1)where U = nominal voltage, in volts; C = capacity, in 🕴F; V = volume, in cm3. Studies have demonstrated that this relationship is valid only for a capacitor batch having the same geometric dimensions and manufactured with the same technology. The same studies have led to the conclusion that to evaluate the natural lifetime of electrolytic capacitors, the endurance test at nominal voltage is inadequate. Since these tests are rarely utilized in permanent operation conditions, the so-called " lifetime" studies undertaken at nominal voltage and maximum operation temperature (having the aim to estimate the total natural lifetime) will lead to completely false results. The flow of current during the charge/discharge cycle of the capacitor causes the internal temperature to rise. The heat generated is transmitted from the core to the surface of the capacitor body, but not all the heat generated can escape. The excess heat results in a rise in the internal temperature of the capacitors which causes the electrolyte to evaporate gradually. Degradation in the oxide layer can be attributed to crystal defects that occur because of the periodic heating and cooling during the capacitor’s duty cycle, as well as stress, cracks, and installation-related damage. These breakdowns, which accelerate the degradation, have been attributed to the duty cycle, the charge/discharge cycle during operation [2].

Further another simultaneous phenomenon is the increase in the internal pressure [3] due to an increased rate of chemical reactions, which can again be attributed to the internal temperature increase in the capacitor. This pressure increase can ultimately lead to the capacitor popping. When aluminium electrolytic capacitors are used in power supplies and signal filters, degradation in the capacitors increases the impedance path for the AC current and decrease in capacitance introduces ripple voltage on top of the desired DC voltage. Continued degradation of the capacitor leads the converter output voltage to drop below specifications affecting downstream components. In some cases, the combined effects of the voltage drop and the ripples may damage the converter and downstream components leading to cascading failures in systems and subsystems.

a) b)

Figure 1 a) Simplified electrical lumped parameter model of impedance of an electrolytic capacitor. b) Detailed Lumped Parameter Model [4]. The ESR (Figure 1) dissipates some of the stored energy in the capacitor. In spite of the dielectric insulation layer between a capacitor’s plates, a small amount of ‘ leakage’ current flows between the plates. For a good capacitor operating nominally this current is not significant, but it becomes larger as the oxide layer degrades during operation. An ideal capacitor would offer no resistance to the flow of current at its leads. However, the electrolyte, aluminium oxide, space between the plates and the electrodes combined produces a small equivalent internal series resistance. A detailed lumped parameter model - derived for an electrolytic capacitor under thermal overstress condition - is shown in Figure 1b. R1 is the combined series and parallel resistances in the model; RE is the electrolyte resistance. The combined resistance of R1 and RE is the equivalent series resistance of the capacitor, and C is the total capacitance of the capacitor. It has been observed [4] that the capacitance and ESR value depends of the electrolyte resistance RE. A primary reason for wear out in aluminium electrolytic capacitors is due to vaporization of electrolyte [5] and degradation of electrolyte due to ion exchange during charging/discharging [2, 3], which, in turn leads to a drift in the two main electrical parameters of the capacitor: (1) the equivalent series resistance (ESR), and (2) the capacitance (C). The ESR of a capacitor is the sum of the resistance due to aluminium oxide, electrolyte, spacer, and electrodes (foil, tabbing, leads, and ohmic contacts) [6, 7]. The health of a capacitor is often indicated by the values of these two parameters. There are certain industry standard thresholds for these parameter values, upon crossing these threshold barrier the component is considered unhealthy to be used in a system, i. e., the component has reached its end of life, and should be immediately replaced before further operations [8-10].

Characteristics

The miniaturization has led to the reduction of the foil surface. To increase the foil surface, the chemical or the electrochemical ruggedness is utilized, which allows obtaining higher capacities for the same volume, and for relatively harder reliability conditions. The capacity of this capacitor type strongly depends on voltage, temperature and frequency. Because of the bad electrolyte conductivity at temperatures under 0🎘C, the operational capacity is strongly affected (growth of the capacitor impedance, expressed by increased apparent resistance and dissipation factor values, and by an increased apparent series resistance, respectively). The alternating current passing through the equivalent series resistance can heat so much the aluminium electrolytic capacitor (in spite of reduced environmental temperature), that it is not possible to maintain its capacitive properties necessary for the system operation. As a result, the capacity variation with temperature is an important quality criterion. To increase the lifetime and the reliability of a capacitor, it is recommended that they operate at the lowest possible temperature. For the same reason it is recommended to mount this capacitor type in areas with the lowest environmental temperature. The highest storage temperature is +40°C, but an operating temperature between 0°C and +25°C should be preferred. Other disadvantages of the electrolytic capacitors are: an important leakage current (as a consequence of the imperfect closing device current), a strong dependence on temperature, and an important dissipation factor. The most important parameters are the impedance and the leakage current (Figure 7. 8), but also the capacity variation $\Delta C/C$ and tan δ. The time variation of the residual current is determined especially by the metal impurities of the aluminium foil and by the dielectric porosity. The leakage current dependence on voltage and the time variation are determined by the applied voltage during the oxidation of aluminium foil, by impurities, and by the exchange effect between dielectric and impregnation electrolyte [11]. The temperature influence is much greater than that of the operating voltage. To the environmental temperature, the self-heating due to the loading in alternating current is added, so that for the aging speed the sum (environmental temperature plus self heating) is decisive. The variation behavior at high temperatures furnishes valuable data on the reliability. The stability of the electrical parameters of electrolytic capacitors is good only if the capacitors are currently operating. A long storage (1 to 2 years) contributes to the growth of the leakage current; but–after applying for some minutes the correct voltage–the leakage current will stabilize at a very small value (new forming process, reactivating). One may say that a capacitor is in a conserving state if the voltage applied is smaller than 0. 15 UN (UN = nominal voltage). Main types of failuresDuring the operation time, the electrolytic capacitors are submitted to a multitude of stresses. To evaluate the quality and reliability, we must consider not only the electrical stresses due to the voltage and current, but also the mechanical and microclimatic influences, caused mainly by the temperature and humidity of the air [11-13]. The main factors that influence the reliability are oxide layer, impregnation layer and foil porosity. At oxide forming–for example–various hydrate modifications can appear. The conductivity of the impregnating electrolyte works directly on the loss factor of impedance, on the chemical combinations and on the stability of electrical values. Capacitors with high stability, reduced dimensions and reduced corrosion sensitivity, having simultaneously reduced dissipation factors and impedances may be obtained by using electrolytes with high ionic mobility, even in poor water media. The depositing volume of the electrolyte influences directly the lifetime. Poor encapsulation leads to a rapid modification of the electrical parameters: a diminution of the electrolyte quantity or a modification of its consistency lead to a growth of the loss factor, a diminution of the capacity and a growth of the impedance. Generally, ceramic capacitors are not more reliable than aluminum electrolytic capacitors (which may self-heal). Since high-capacitance ceramic capacitors may develop microcracks, aluminum electrolytic capacitors are preferred for high capacitance values. Causes of failuresThe main causes of failure for electrolytic capacitors are: Breakdown voltage; Important leakage currents leading to breakdown; Capacity diminishing; High loss factor. In most cases, the last two causes occur simultaneously. The lifetime and reliability of aluminium electrolytic capacitors are strongly dependent on temperature. ConclusionsAll the failure/degradation phenomenon mentioned may act simultaneously based on the operating conditions of the capacitors. Electrolyte evaporations is caused either due to increase in internal core temperature or external surrounding temperature. Both phenomenon lead to the same degradation mode, caused either by the high electrical stress or thermal stress, respectively.