

1 General Description of Aluminum Electrolytic Capacitors

1-1 The Principle of Capacitor

The principle of capacitor can be presented by the principle drawing as in Fig.1-1.

When a voltage is applied between the metal electrodes placed opposite on both surfaces of a dielectric, electric charge can be stored proportional to the voltage.

$$Q = C \cdot V$$

Q : Quantity of electricity (C)

V : Voltage (V)

C : Capacitance (F)

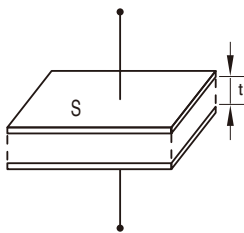


Fig.1-1

C, called the capacitance of capacitor, is expressed by the following expression with the electrode area $S[m^2]$, the electrode spacing $t[m]$ and the dielectric constant of dielectric “ ϵ ”:

$$C[F] = \epsilon_0 \cdot \epsilon \cdot \frac{S}{t}$$

ϵ_0 : Dielectric constant in vacuum ($=8.85 \times 10^{-12} F/m$)

The dielectric constant of an aluminum oxide film is 7 to 8. Larger capacitances can be obtained by enlarging the electrode area S or reducing t .

Table 1-1 shows the dielectric constants of typical dielectrics used in the capacitor. In many cases, capacitor names are determined by the dielectric material used, for example, aluminum electrolytic capacitor, tantalum capacitor, etc.

Table 1

Dielectric	Dielectric Constant	Dielectric	Dielectric Constant
Aluminum oxide film	7 to 8	Porcelain (ceramic)	10 to 120
Mylar	3.2	Polystyrene	2.5
Mica	6 to 8	Tantalum oxide film	10 to 20

Although the aluminum electrolytic capacitor is small, it has a large capacitance. It is because the electrode area is roughened by electrochemical etching, enlarging the electrode area and also because the dielectric is very thin.

The schematic cross section of the aluminum electrolytic capacitor is as in Fig.1-2.

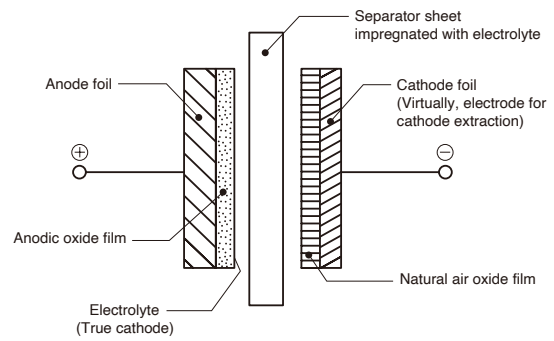
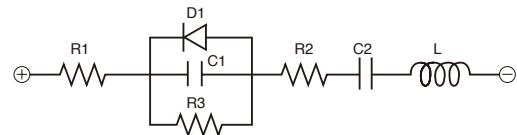


Fig.1-2

1-2 Equivalent Circuit of the Capacitor

The electrical equivalent circuit of the aluminum electrolytic capacitor is as presented in the following figure.



R1 : Resistance of terminal and electrode

R2 : Resistances of anodic oxide film and electrolyte

R3 : Insulation resistance because of defective anodic oxide film

D1 : Oxide semiconductor of anode foil

C1 : Capacity of anode foil

C2 : Capacity of cathode foil

L : Inductance caused by terminals, electrodes, etc.

2 About the Life of an Aluminum Electrolytic Capacitor

2-1 Concept of Life Estimation

2-1-1 Estimation of life with minimal ripple current (negligible).

Generally, the life of an aluminum electrolytic capacitor is closely related with its ambient temperature and the life will be approximately the same as the one obtained by Arrhenius' equation.

$$L = L_0 \times 2^{\left(\frac{T_0 - T}{10}\right)} \dots \dots \dots (1)$$

Where L : Life at temperature T

L_0 : Life at temperature T_0

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2-1-2 Estimation of life considering the ripple current.

The ripple current affects the life of a capacitor because the internal loss (ESR) generates heat. The generated heat will be :

$$P = I^2R \dots\dots\dots(2)$$

Where I : Ripple current (Arms)
R : ESR (Ω)

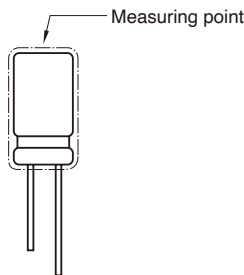
With increase in the temperature of the capacitor:

$$\Delta T = \frac{I^2 \times R}{A \times H} \dots\dots\dots(3)$$

Where ΔT : Temperature increase in the capacitor core(deg.)

I : Ripple current (Arms)
R : ESR (Ω)
A : Surface area of the capacitor (cm²)
H : Radiation coefficient (Approx. 1.5 to 2.0 × 10⁻³W/cm²×°C)

The above equation (3) shows that the temperature of a capacitor increases in proportion to the square of the applied ripple current and ESR, and in inverse proportion to the surface area. Therefore, the amount of the ripple current determines the heat generation, which affects the life. The value of ΔT varies depending on the capacitor types and operating conditions. The usage is generally desirable if ΔT remains less than 5°C. The measuring point for temperature increase due to ripple current is shown below ;



Since it is actually difficult to measure the temperature increase at the capacitor core, the following table is provided for conversion from the surface temperature increase to the core temperature increase.

Table 2-1

Case diameter	to 10	12.5 to 16	18
Core / Surface	1.1	1.2	1.25

①The life estimation formula that considers ambient temperature and temperature rise due to ripple is derived as follows by modifying formula (1).

$$L = L_d \times 2 \left(\frac{T_0 - T}{10} \right) \times K \left(\frac{-\Delta T}{10} \right) \dots\dots\dots(4)$$

Where L_d : Life at DC operation (h)
at Upper category temperature
K : Ripple acceleration factor
(K=2, within allowable ripple current)
T₀ : Upper category temperature (°C)
T : Operating temperature (°C)
ΔT : Temperature increase at capacitor core (deg.)

②The life estimation formula based on Guaranteed life (when rated ripple current is superimposed at upper category temperature) is derived as follows by modifying formula (4).

$$L = L_r \times 2 \left(\frac{T_0 - T}{10} \right) \times K \left(\frac{\Delta T_0 - \Delta T}{10} \right) \dots\dots\dots(5)$$

Where L_r : Guaranteed life
(Life at the upper category temperature with the rated ripple current [h])
ΔT₀ : Temperature increase at capacitor core, at the upper category temperature (deg.)

③Life estimation formula considering ambient temperature and ripple current is derived as follows by using equation (3) to transform equation (5) into equations for I, I₀, ΔT₀.

$$L = L_r \times 2 \left(\frac{T_0 - T}{10} \right) \times K \left\{ 1 - \left(\frac{I}{I_0} \right)^2 \right\} \times \frac{\Delta T_0}{10} \dots\dots\dots(6)$$

Where I₀ : Rated ripple current at the upper category temperature (Arms)
I : Applied ripple current (Arms)

Use below ΔT₀ value at each category highest temperature when calculating life expectancy using equation (5) or (6).

Aluminum Electrolytic Capacitors	85	: 10deg
	105 to 135	: 5deg
	150	: 3deg
Polymer hybrid type aluminum Electrolytic Capacitors	105	: 15deg
	125	: 10deg
	135	: 10deg
	150	: 5deg

The life expectancy formula shall in principle be applied to the temperature range between the ambient temperature of +40°C and upper category temperature. (Temperature conditions below +40°C are uniformly treated as +40°C.)

The expected life time shall be about fifteen years at maximum as a guide in terms of deterioration of the sealant. Also, please note that the calculation results calculated by the above formulas (4), (5), and (6) are not guaranteed values.

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2-2 Practical Examples of Life Expectancy

By using the life estimation formula (6), the capacitor's guaranteed time L_r (category upper limit temperature T_0 , rated ripple current I_0) can be converted to operating time L under actual usage conditions (temperature T , ripple current I).

When considering whether a certain capacitor can be applied to a mission profile (a combination of multiple conditions of temperature, current, and operating time) that assumes actual use, calculate L for each profile condition using formula (6), and it can be assumed that the capacitor is applicable for profile conditions if the ratio of the total value of actual operating time L_c to the total value of L (life consumption rate L_{et}) is within 100%.

(Since the calculation result is not a guaranteed value, please make a decision after thorough testing regarding profile application.)

[Calculation example]

Calculate whether the RKC series 80V1600 μ F (Data A) is applicable to the mission profile (Data B).

Data A (Basic sample data)

Item	: 80V 1600 μ F ϕ 18 x 40L RKC series
T_0	= 135°C
ΔT_0	= 5deg
I_0	= 3.82Arms at 135°C, 100kHz
L_r	(Guarantee = 2000hours at 135°C time)

Data B (Mission profile)

	T (Ambient temperature)	I (Ripple current at 100kHz)	L_c (Operating time)
Condition1	80°C	2.00Arms	5000h
Condition2	120°C	3.00Arms	3000h
Condition3	40°C	0.00Arms	123400h

[Condition1]

Calculate L_1 (80°C, 2.00Arms) by using $T_0=135^\circ\text{C}$, $I_0=3.82\text{Arms}$, $L_r=2000\text{h}$, $\Delta T_0=5\text{degC}$

$$L_1 = 2000 \times \left[2^{\frac{(135-80)}{10}} \times 2^{\frac{1-(2.00/3.82)^2}{5} \times (5/10)} \right] = 116400[\text{h}]$$

Life consumption rate L_{et1} of actual operating time L_{c1} (=5000h) against L_1 is calculated as,

$$L_{et1} = 100 \times (L_{c1} / L_1) = 100 \times (5000 / 116400) = 4.30[\%]$$

[Condition2]

Calculate L_2 (120°C, 3.00Arms) by using $T_0=135^\circ\text{C}$, $I_0=3.82\text{Arms}$, $L_r=2000\text{h}$, $\Delta T_0=5\text{degC}$

$$L_2 = 2000 \times \left[2^{\frac{(135-120)}{10}} \times 2^{\frac{1-(3.00/3.82)^2}{5} \times (5/10)} \right] = 6461[\text{h}]$$

Life consumption rate L_{et2} of actual operating time L_{c2} (=3000h) against L_2 is calculated as,

$$L_{et2} = 100 \times (L_{c2} / L_2) = 100 \times (3000 / 6461) = 46.4[\%]$$

[Condition3]

Calculate L_3 (40°C, 0.00Arms) by using $T_0=135^\circ\text{C}$, $I_0=3.82\text{Arms}$, $L_r=2000\text{h}$, $\Delta T_0=5\text{degC}$

$$L_3 = 2000 \times \left[2^{\frac{(135-40)}{10}} \times 2^{\frac{1-(0.00/3.82)^2}{5} \times (5/10)} \right] = 2048000[\text{h}]$$

Life consumption rate L_{et3} of actual operating time L_{c3} (=123400h) against L_3 is calculated as,

$$L_{et3} = 100 \times (L_{c3} / L_3) = 100 \times (123400 / 2048000) = 6.03[\%]$$

Therefore, the total value L_{et_all} of the life consumption rate of each profile is calculated as follows.

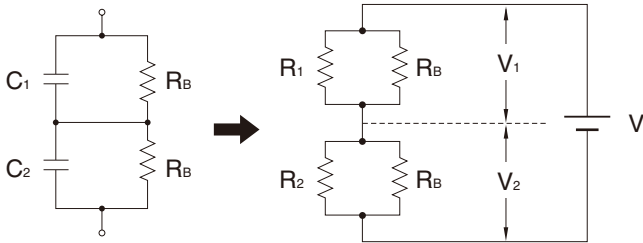
$$L_{et_all} = L_{et1} + L_{et2} + L_{et3} = 4.30[\%] + 46.4[\%] + 6.03[\%] = 56.8[\%]$$

Therefore, since it is less than 100%, RKC series 80V1600 μ F is presumed to be applicable to this profile.

3 To calculate Balance when connecting in series

3-1 Circuit layout

Circuit for connecting two capacitors (C1, C2) in series and equivalent circuit can be illustrated as below figure. Formula to calculate a balance resistance R_B of below figure is shown as follows.



Following are the preconditions of the circuit.

- ① V_2 shall be the rated voltage ($=V_0$). ($V_1 < V_2$)
- ② V shall be a times $V_0 \times 2$. $V = 2aV_0$ ($a < 1$)
- ③ R_2 shall equal $R_1 \times b$. ($b < 1$) (1)

3-2 Formulas to calculate $[R_B]$

3-2-1 Following formula can be established from balanced condition.

$$V_1 \left[\frac{1}{R_1} + \frac{1}{R_B} \right] = V_2 \left[\frac{1}{R_2} + \frac{1}{R_B} \right] \quad (2)$$

3-2-2 Following formula can be established from preconditions.

$$V_2 \leq V_0 \quad (3)$$

$$V_1 = V - V_2 \quad (4)$$

$$= 2aV_0 - V_2 \quad (4')$$

3-2-3 Put formulas (1), (3) and (4') in formula (2).

$$(2aV_0 - V_2) \left[\frac{R_1 + R_B}{R_1 \times R_B} \right] = V_2 \left[\frac{bR_1 + R_B}{bR_1 \times R_B} \right]$$

$$2abV_0(R_1 + R_B) = V_2 \{b(R_1 + R_B) + bR_1 + R_B\}$$

$$2ab(R_1 + R_B) \leq 2bR_1 + (1+b)R_B$$

Accordingly, balance resistance R shall be the following formula.

$$R_B \leq 2bR_1 \frac{(1-a)}{(2a-1) \times b - 1} \quad (5)$$

3-3 Calculation Example

Calculate the value of the balance resistance in the case of connecting two 400V 470 μ F (LC standard value : 1.88mA) capacitors in series.

$$R_1 = \frac{400(V)}{1.88(mA)} = 213(k\Omega)$$

If $a=0.8$, $400(V) \times 2 \times 0.8 = 640(V)$ as an impressed voltage.

If $b=2$, $R_2 = b R_1 = 426(k\Omega)$, $LC = 0.94(mA)$.

Balance resistance R_B will be.

$$R_B \leq 2 \times 2 \times 213(k\Omega) \frac{(1-0.8)}{(2 \times 0.8) \times 2 - 1} = 852(k\Omega)$$

4 Regarding Recovery Voltage

• After charging and then discharging the aluminum electrolytic capacitor, and further causing short-circuit to the terminals and leave them alone, the voltage between the two terminals will rise again after some interval. Voltage caused in such case is called recovery voltage. Following is the process that causes this phenomenon :

- When the voltage is impressed on a dielectric, electrical transformation will be caused inside the dielectric due to dielectric action, and electrification will occur in positive-negative opposite to the voltage impressed on the surface of the dielectric. This phenomenon is called polarization action.
- After the voltage is impressed with this polarization action, and if the terminals are discharged till the terminal voltage reaches 0 and are left open for a while, an electric potential will arise between the two terminals and thus causes recovery voltage.
- Recovery voltage comes to a peak around 10 to 20 days after the two terminals are left open, and then gradually declines. Recovery voltage has a tendency to become bigger as the component (stand-alone base type) becomes bigger.
- If the two terminals are short-circuited after the recovery voltage is generated, a spark may scare the workers working in the assembly line, and may put low-voltage driven components (CPU, memory, etc.) in danger of being destroyed. Measures to prevent this is to discharge the accumulated electric charge with resistor of about 100 to 1k Ω before using, or ship out by making the terminals in short-circuit condition by covering them with an aluminum foil at the production stage. Please consult us for adequate procedures.

5 Electrode Foil Development Technology

5-1 Corrosion inhibition of cathode foil

Inactive treatment is implemented to ensure long life by inhibiting natural corrosion of the cathode foil. Fig. 3-1 shows its effects with values of the polarization resistance inversely proportional to the corrosion rate using the AC impedance method (FRA). This indicates that the cathode foil used in the High reliability capacitors has the polarization resistance higher than that of the conventional capacitors owing to corrosion inhibition.

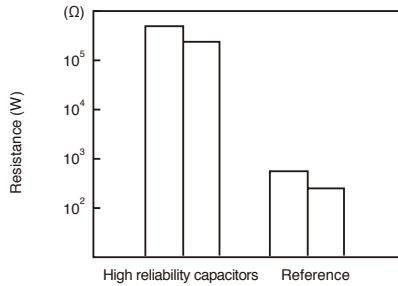


Fig. 3-1

5-2 Sealing material permeability of electrolyte

To ensure long life, a low permeable lactone solvent for the sealing material is used as the main solvent of the electrolyte of the High reliability capacitor. Fig. 3-2 shows the test results on the permeability obtained by changing the weight of the capacitors produced with different types of electrolytes at a high temperature.

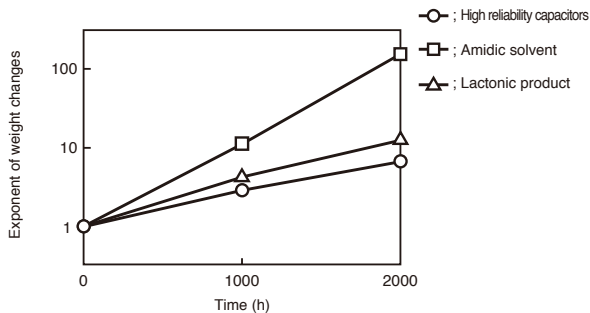


Fig. 3-2

5-3 Airtightness of sealing material

Since the electrolyte is stable for hours, the key element for capacitor's life is the sealing material. By optimizing the crosslinking density of the sealing material polymer, the sealing material of the High reliability capacitor attains its long life with electrolyte permeability less than that of the conventional capacitors.

Fig. 3-3 shows the test results on the airtightness of the sealing material obtained by changing the weight of the capacitors at a high temperature, producing capacitors with the conventional sealing material and improved one both containing the electrolyte used in the High reliability capacitor.

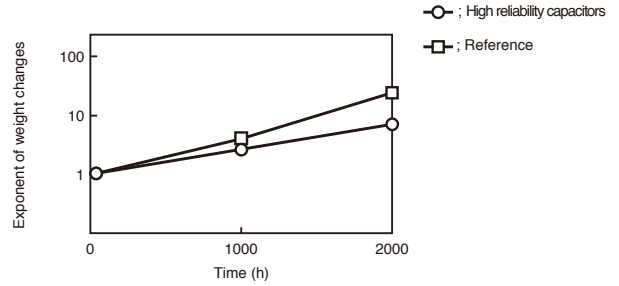


Fig. 3-3

5-4 Long-time stability of electrolyte

The electrolyte used in the High reliability capacitor is stable with low initial resistivity and small secular changes at a high temperature. Fig. 3-4 shows change in resistivity at 105°C.

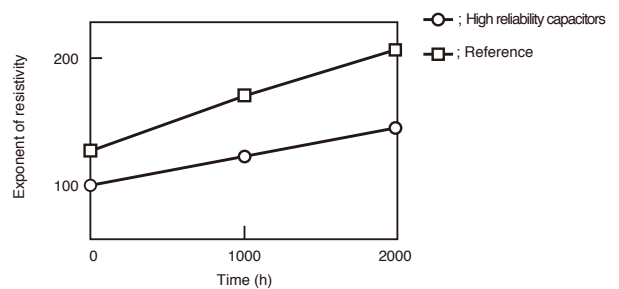


Fig. 3-4

5-5 Dielectric formation voltage and leakage current characteristics of anode foil

To increase the operating life by controlling the gas generation inside capacitor because of 1.5 to 2 times the rated voltage, while that of the previous capacitor is about 1.3 times the rated voltage.

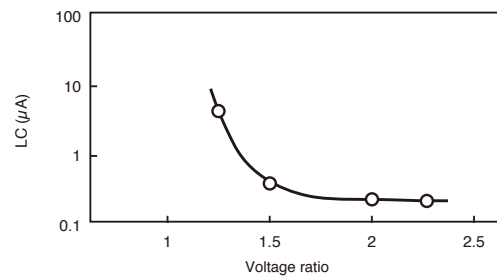


Fig. 3-5

5-6 Lowered ESR of Electrode Foil

To reduce the ESR of electrolytic capacitor, we have improved our chemical conversion technology for anode foil to develop lower ESR electrode foil compared to the conventional product as shown in Fig. 3-6

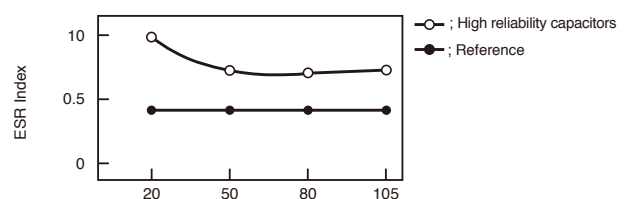


Fig. 3-6 ESR Index of Anode Foil

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