2-9-5 Ripple Current and Life

The tan δ of the aluminum electrolytic capacitor is larger than other types such as film capacitors, and heat generates inside electrolytic capacitors due to power loss when ripple current is applied. Heat generation effects the life of the capacitor because it causes a temperature rise.

1) Ripple Current and Heat Generation

The power loss due to ripple current being applied along with a DC voltage can be calculated by the following formula :

$$W = W_{AC} + W_{DC}$$

$$W = I_{AC}^2 \times Re + V_{DC} \times I_{DC} \quad \cdots\cdots\cdots (2 - 7)$$

- W : Consumption of electricity by the capacitor (W)
- W_{AC} : Power loss due to ripple current (W)
- W_{DC} : Power loss due to DC (W)
- I_{AC} : Ripple current (A)
- Re : E.S.R. of the capacitor
- V_{DC} : DC Voltage (V)
- I_{DC} : Leakage Current (A)

If the DC voltage is below the rated voltage, the leakage current is extremely small and becomes $W_{AC} >> W_{DC}$. From this, power loss can be calculated by the following formula :

$$W = I_{AC}^2 \times Re \quad \cdots\cdots\cdots (2 - 8)$$

The external temperature of the capacitor rises to a point where the internal heat generation balances with the heat radiation. The temperature rise up to a balance point can be given by the following formula:

$$I_{AC}^2 \times Re = \beta \times A \times \Delta t \quad \cdots\cdots\cdots (2 - 9)$$

$$\Delta t = \frac{I_{AC}^2 \times Re}{\beta \times A} \quad \cdots\cdots\cdots (2 - 10)$$

β : Heat Radiation Constant (10^{-3}W / °C·cm^2)
A : Surface Area (cm^2)

When the size of the capacitor is $\phi D \times L$:

$$A = \frac{\pi}{4} D (D + 4L) \quad \cdots\cdots\cdots (2 - 11)$$

The surface area can be figured from the above equation.
Δt = Temperature rise of ripple (°C)

The relationship between internal resistance "Re," capacitance "C" and tanδ is as follows :

$$Re = \frac{\tan\delta}{\omega C} \quad \cdots\cdots\cdots (2 - 12)$$

However, according to $\omega = 2\pi f$, ... (2 - 13)

$$\Delta t = \frac{I_{AC}^2 \times Re}{\beta \times A} = \frac{I_{AC}^2 \times \tan\delta}{\beta \times A \times \omega C}$$

The heat radiation constant (β) and temperature rise multiplier, which is temperature rise ratio calculated by temperature rise at the surface Δts divided by at the core of element Δtc and is expressed as α, is as shown in Table 2-4.

Table 2-4

Case dia (mm)	5 or less	6.3	8	10	12.5	16	18	20	22	25	30	35	40
β	2.18	2.16	2.13	2.10	2.05	2.00	1.96	1.93	1.88	1.84	1.75	1.66	1.58
α	1.0		0.94	0.90	0.85	0.80	0.77	0.75	0.74	0.71	0.67	0.64	0.62

α :Temperature rise ratio calculated $\alpha = \Delta ts / \Delta tc$

β : Heat radiation constant (10^{-3}W / °C·cm^2)

2) Frequency Coefficient of Allowable Ripple Current

Equivalent series resistance of aluminum electrolytic capacitor (Re) is frequency dependence. Higher the frequency, lower the ESR. Assuming that temperature rise due to ripple current at a frequency of (fx) and at a frequency of (fo) are same, when (Ro) is ESR at a frequency of (fo) and (Rx) is ESR at a frequency of (fx). The following equation would be set.

$$I_0^2 \times R_0 = I_x^2 \times R_x$$

$$\therefore I_x = \sqrt{\frac{R_0}{R_x}} \times I_0 \quad \cdots\cdots\cdots (2 - 14)$$

Thus, $\sqrt{R_0/R_x}$ becomes the frequency coefficient Kf. Table 2-5 shows examples of frequency coefficients.

Table 2-5 Frequency coefficient of allowable ripple courrent <Example>

・Snap - in terminal type capacitors (For input smoothing circuit)

Frequency (Hz)		50	60	120	300	1k	10k	50k~
Frequency coefficient (Kf)	16~100V	0.88	0.90	1.00	1.07	1.15	1.15	1.15
	160~250V	0.81	0.85	1.00	1.17	1.32	1.45	1.50
	315~450V	0.77	0.82	1.00	1.16	1.30	1.41	1.43

・Lead type capacitors (For output smoothing circuit)

Rated voltage(V)	Frequency (Hz) / Cap.(μF)	50	120	300	1k	10k~
6.3~100V	~56	0.20	0.30	0.50	0.80	1.00
	68~330	0.55	0.65	0.75	0.85	1.00
	390~1000	0.70	0.75	0.80	0.90	1.00
	1200~15000	0.80	0.85	0.90	0.95	1.00

3) Temperature Coefficient of Allowable Ripple Current

The applicable ripple current value below the maximum operating temperature must be limited by specified ripple temperature rise at the center of element per ambient temperature.(Table 2-6.)

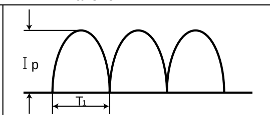
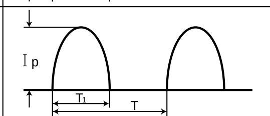
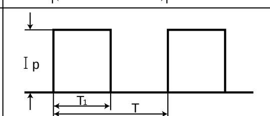
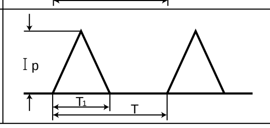
Table 2-6 Limit of element core temperature rise
(Over 315 Voltage with Snap-in terminal type capacitors)

Ambient Temperature (°C)	40	55	65	85	105
Δtc (°C)	30	30	25	15	5

4) The method which seeks for effective current value from Ripple current wave form

In case that a ripple, which ripple current of high frequency switching is superimposed upon commercial frequency ripple, is applied, such as in switching power supplies, inverter type supplies and active filter circuits, there is a method to obtain the effective value from the waveform pattern in Table 2-7 by finding the similar waveform observed in actuality.

Table 2 - 7 Current Wave and Caluculation Expression for Effective Value

	Wave form	Formula of effective value
①		$I_{rms} = \frac{I_P}{\sqrt{2}}$
②		$I_{rms} = I_P\sqrt{\frac{T_1}{2T}}$
③		$I_{rms} = I_P\sqrt{\frac{T_1}{T}}$
④		$I_{rms} = I_P\sqrt{\frac{T_1}{3T}}$

Effective ripple value is calculated from the wave form of ripple, which ripple current of high frequency switching (I_H) is superposed upon ripple current of commercial frequency (I_L)(as in Figure 2-17), by dividing it into each frequency component.

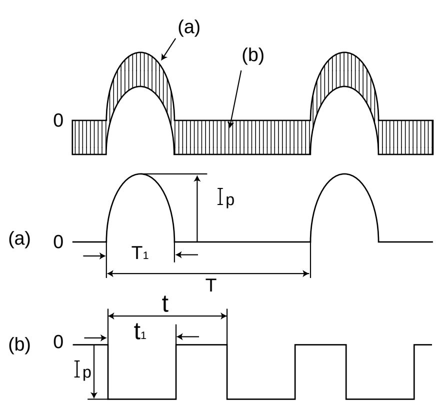


Fig. 2 - 17

Setting Model ② as the ripple current for a low frequency component (I_L):

$$I_L = I_P \times \sqrt{\frac{T_1}{2T}} \quad \cdots\cdots\cdots \ (2 - 15)$$

Setting Model ③ as the ripple current for a high frequency component (I_H) :

$$I_H = I_P \times \sqrt{\frac{t_1}{t}} \quad \cdots\cdots\cdots \ (2 - 16)$$

The equivalent series resistance of aluminum electrolytic capacitors has frequency characteristics; so if the frequency is different from the standard, it is converted to meet the standard frequency. If the frequency coefficient for low frequency components is labeled "K_{fL}" and the frequency coefficient for high frequency componentsis labeled "K_{fH}, " the synthetic ripple "I_n" converted to the standard frequency is :

$$I_n = \sqrt{\left(\frac{I_L}{K_{fL}}\right)^2 + \left(\frac{I_H}{K_{fH}}\right)^2} \quad \cdots\cdots\cdots \ (2 - 17)$$

5) Estimating Temperature Rise due to Ripple Current

Power loss is proportional to the second power of ripple current. If the temperature rises at the middle of the element, when the permissible ripple current "I_o" (A), is labeled "Δt_o," the temperature rise when ripple current "I_n" (A) is applied would be as follows :

$$\Delta t_n = \left(\frac{I_n}{I_0}\right)^2 \times \Delta t_0 \quad \cdots\cdots\cdots \ (2 - 18)$$

The temperature rise "Δt_o" for a 105°C snap-in terminal type capacitor is approximately 5°C. However, since the equivalent series resistance "R_e" of aluminum electrolytic capacitors differs according to the temperature and because the ripple current wave - form has many complex frequency components in actuality, we recommend that the temperature rise is actually measured with thermocouples.

2-9-6 Estimated Life

The estimated life of an aluminum electrolytic capacitor is represented multiplying the specified life time on Nichicon catalog F_T, F_1, and Fu as explained in 2-9-1. Shown below are the formulase for obtaining the expected life for the large can type aluminum electrolytic capacitors and the miniature aluminum electrolytic capacitors. For further details, consult Nichicon.

(Large can type)
Formula 2-19 is for obtaining the estimated life of a large can type electrolytic capacitor.
For the formula for screw terminal capacitors, please consult Nichicon.

$$L_n = L_o \times 2^{\frac{T_o - T_n}{10}} \times 2^{1 - \frac{\Delta t_n}{K}} \quad \Delta t_n = t_o \times \left(\frac{I_n}{I_m}\right)^2 \cdots\cdots\cdots \ (2 - 19)$$

L_n: Estimated life (h) at ambient temperature of Tn (°C) with a ripple current In (Arms) applied.

L_o: Specified life time (h) at maximum operating temperature To (°C) with the specified maximum allowable ripple current Im (Arms) at To (°C) applied

T_o: Maximum operating temperature of the capacitor (°C)

T_n: Ambient temperature of the capacitor (°C)

$\Delta$to : The internal temperature rise (°C) of the capacitor at ambient temperature To (°C) with the maximum allowable ripple current Im (Arms) at To applied

Δt_n : The internal temperature rise (°C) of the capacitor at ambient temperature Tn (°C) with the actually applied ripple current In (Arms)

K: Acceleration coefficient of temperature rise due to ripple [refer to the chart below ; applicable coefficient is for the range below the maximum operating temperature To (°C)]

※The formula is applicable for the range of ambient temperature Tn of 40°C and the maximum operating temperature To. Please note that fifteen years is generally considered to be the maximum for the estimated life obtained by the above formula.

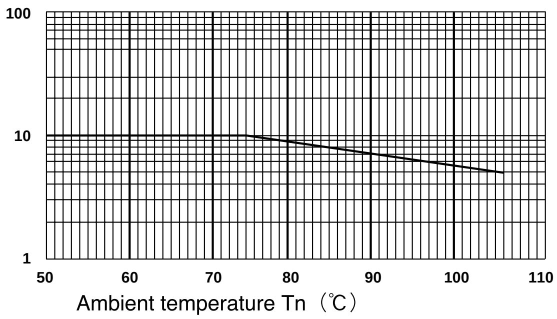


Fig 2-18 Acceleration coefficient of temperature rise due to ripple; K

(Miniature type)

There are two formulase for obtaining the estimated life of a miniature aluminum electrolytic capacitor, depending on the life specification of series on Nichicon catalog as shown in formulase 2-20 and 2-21.

(1) Capacitors life time is specified. with rated DC vortage applied only

$$L_n = L \times 2^{\frac{T_0 - T_n}{10}} \times \frac{1}{B_n} \quad \cdots\cdots\cdots \ (2\text{-}20)$$

$$\text{Where } B_n = 2^{\alpha \times \left(\frac{I_n}{I_m}\right)^2 \times 2^{-\left(\frac{T_0 - T_n}{30}\right)}}$$

(2) Capacitors life time is specified with D.C. bias voltage plus rated ripple current.

$$L_n = L_o \times 2^{\frac{T_0 - T_n}{10}} \times 2^{\alpha\left\{1 - \left(\frac{I_n}{I_m}\right)^2 \times 2^{-\left(\frac{T_0 - T_n}{30}\right)}\right\}} \quad \cdots\cdots\cdots \ (2\text{-}21)$$

(2-20) , (2-21) :

$2^{\frac{T_0 - T_n}{10}}$ Tn(°C)≦40 : $2^{\frac{T_0 - 40}{10}}$

$2^{-\left(\frac{T_0 - T_n}{30}\right)}$ **Tn(°C)≦50** : $2^{-\left(\frac{T_0 - 50}{30}\right)}$

Ln:Estimated life time (h) at ambient temperature of Tn (°C) with a ripple current In (Arms) applied.

L :Specified life time (h) at maximum operating temperature T (°C) with the rated DC voltage applied.

Lo:Specified life time (h) at maximum operating temperature T (°C) with the specified maximum allowable ripple current Im (Arms) at T (°C) applied.

To: Maximum operating temperature of the capacitor (°C)

Tn: Ambient temperature of the capacitor (°C)

Im:Rated ripple current (Arms) at maximum operating temperature T (°C)
Im need to be valued in the same frequency as that of the ripple current being used by multiplying specified ripple-frequency coefficient in Nichicon catalog.

In: Ripple current (Arms) actually applied at ambient temperature Tn (°C)

Bn:Acceleration coefficient when ripple In (Arms) is applied at ambient temperature Tn (°C)

α : Life constant
Contact us for details regarding the life constant.

The formula is applicable for the range of ambient temperature Tn of 40°C and the maximum operating temperature To. Please note that calculated life time is for reference only and not guaranteed. Typically, fifteen years is generally considered to be the maximum for the estimated life obtained by the above formula.