Optimize Electrolytic Capacitor Selection

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In applications operating with intermittent ripple current, you can specify a cost-effective, optimum electrolytic capacitor by evaluating its thermal characteristics over time.

Intelligent control is increasingly used in automotive devices where electric drives are now specified for power steering units, water pumps, and air-conditioning compressors. The automotive environment has harsh requirements for temperature, shock, vibration, and ripple current, which are especially important to the selection of electrolytic capacitors. It's important to carefully consider ripple current, as it affects the capacitor heating and thus its life.

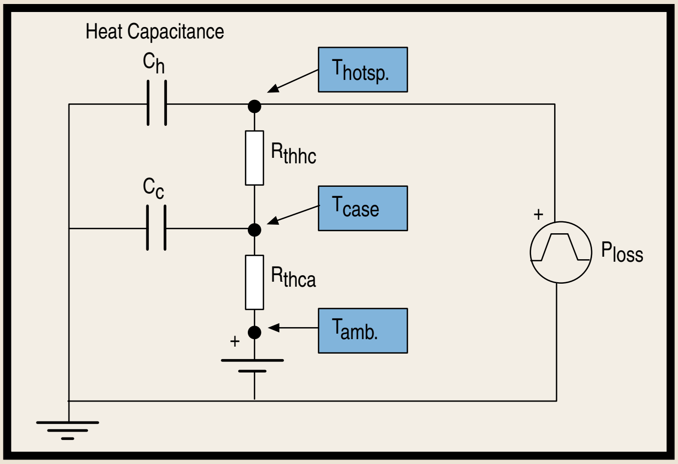

Fig. 1. *Thermal model of a capacitor.*

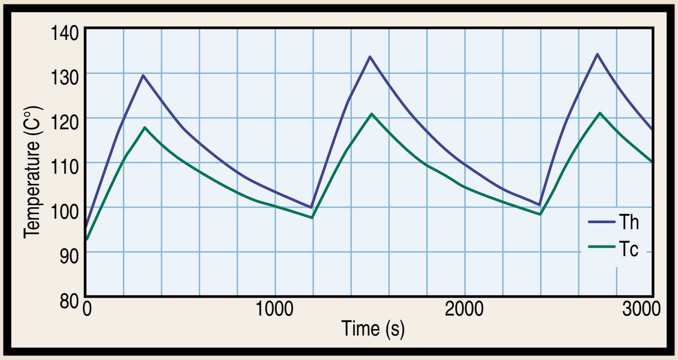

Fig. 2. *Plot of simulated capacitor case and hotspot temperature.*

Many applications only call for maximum ripple current on an intermittent basis—for example, a power steering unit where maximum current only occurs when turning the steering wheel. This allows optimization of the electrolytic capacitor selection. Otherwise, selecting the capacitor to meet the continuous peak current requirement adds unnecessary costs.

To take advantage of capacitor optimization without compromising quality, designers must have accurate thermal models. However, designers don't need thermal simulation software if the capacitor manufacturer provides the correct data. They can use an ordinary circuit simulation package to make the thermal predictions. Since the "circuits" are relatively simple, designers can even use the free student versions of the thermal software.

Fig. 1 shows the thermal model of a capacitor; however, the capacitor manufacturer must provide the "heat capacitance" and thermal resistance figures. For example, the thermal figures for the Evox Rifa PEG126KL427CM (2700µF, 40Vdc) capacitor are:

R_{thhc} = 7.7°C/W (thermal resistance, capacitor internal hotspot to case)

R_{thca} = 18°C/W (thermal resistance, capacitor case to ambient, no forced air)

C_h = 21 J/°C (heat capacitance, winding)

C_c = 2.5 J/°C (heat capacitance, case)

Consider the following application example:

- Capacitor on for 5 min
- Capacitor current 20A, 5 kHz
- Capacitor off for 15 min
- Ambient temperature 93°C
- ESR = 8.7 mΩ (calculated from capacitor characteristic data)
- Power loss = $I_{rms}^2 \times ESR$ = 3.5W

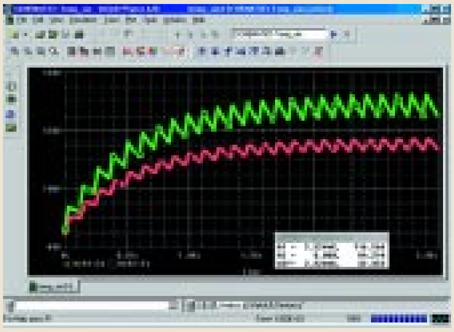

Fig. 3. *Capacitor thermal simulation as run on a PC using OrCad Pspice.*

When these conditions are set up in PSpice, the "voltage" measured at the nodes shown in **Fig. 1**, on page 34, is actually the case and hotspot temperature. The output for this example is plotted in **Fig. 2**, on page 34, where the horizontal axis indicates time and the vertical axis, temperature. The capacitor is actually operating above its continuous current rating. This is acceptable because under these intermittent conditions the peak internal hotspot temperature is below the maximum allowed limit. Thus, you can use a smaller, less expensive capacitor—compared with what would be specified if trying to meet the intermittent current on a continuous basis.

Estimated Capacitor Life

The operational lifetime of an electrolytic capacitor is based mainly on the rate of electrolyte diffusion during operation. Many factors (electrolyte type, quality of the sealing system, temperature, etc.) affect the life. These factors are important for the capacitor selection. Once a type is chosen for evaluation, the capacitor manufacturer can give baseline life figures that are used to determine the actual expected operational life (L_{op}) under any circumstance.

In the case of continuous operation, the operational life calculation is relatively simple.

$$L_{op} = A \times 2^{\left(\frac{(85-T_h)}{C}\right)} \quad (1)$$

T_h = Capacitor temperature
A = Specified L_{op} at T_h = 85°C
C = Constant of temperature dependence (for the particular capacitor under study)

For intermittent operation, you must perform an integration over one temperature cycle.

$$L_{op} = 1/ (\text{ mean } [1/ L_{op}''(t)]) \quad (2)$$

Where:
mean $[1/ L_{op}''(t)]$ = [mean value over time]

$$\frac{1}{\Delta t \times A} \times \int 2^{\frac{-(85-T_h)}{C}} dt \quad (3)$$

(integration over 1 temp. cycle, Δt = 1 cycle)

For the capacitor in our example:

A = 97kh at T_h = 85°C (expected operational life at 85°C) (kh = thousands of hours)

C = 11°C (rate of temperature dependence)

In the intermittent condition being studied, the estimated operation life L_{op} = 12kh. Although this may not seem very high, it would be suitable for a power steering unit. For example, a car driven for 100k miles at an average speed of 20 mph corresponds to only 5k hr of operation. Furthermore, the simulation assumes that the steering wheel position is changed 25% of the time throughout the entire 100k miles. However, in real-world conditions, the steering wheel is not turned so frequently. (Corrections during straight-line driving would not count because full steering assist would not be applied in that case.)

Looking at **Fig.3**, you can see an example plot obtained using Pspice software. If you can obtain the correct thermal data from the capacitor manufacturer, it isn't necessary to have thermal simulation software to perform the analysis. **PETech**

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