TN0023
Technical note

Discontinuous flyback transformer description and design parameters

Introduction

The following is a general description and basic design procedure for the discontinuous flyback transformer. It can be useful for further development of an existing design, where some parameters are known, or for communicating changes with a transformer design house.

The flyback transformer can be used in isolated or non-isolated power supplies for almost any output voltage. The discontinuous flyback transformer has a triangular current waveform and commonly uses a 50% duty cycle at full load and minimum input line. A lower duty cycle can be used but the peak and RMS current is higher. A higher duty cycle will involve more complicated means for stability and a lower bandwidth. The frequency is selected based on many considerations - for example a smaller transformer can be used with higher frequency but the switching losses are higher.

The application requirements dictate the design and include minimum AC input voltage, maximum output power (Pomax), efficiency (η), operating frequency (f), output voltage (V_o) and diode drop (V_{do}). Some of the other circuit considerations, which are a result of the design, include switching device current rating, peak current (for peak current limit), switching device drain to source voltage and output rectifier reverse voltage (from maximum input voltage), wire size, and an auxiliary voltage if required.

This technical note presents is one of the many procedures used to design a discontinuous flyback transformer for a low power application. Application requirements are as follows.

1 Inputs

- $V_{in_{min}}$: the minimum DC voltage from the minimum AC input (V)
- $P_{o_{max}}$: maximum output power (W)
- η: efficiency, initially based on experience
- f: operating frequency (Hz).
- V_o: output voltage (V)
- V_{do}: output voltage diode drop (V)
- V_{aux}: auxiliary voltage (V)
- V_{da}: auxiliary voltage diode drop (V)

1.1 Estimate

Choose G_{in} = 0.015 in. A gap size range starting point is about 0.010 to 0.020 in. If the gap is too small the manufacturing tolerances are difficult and if the gap is too large, fringing around the gap can be a problem. Estimate the core size and use the effective core area (A_e).

1.2 Procedure

1. Determine the minimum DC input voltage from the minimum AC voltage minus about 20 V of ripple voltage. Choose a flyback voltage (V_{fl}) equal to the minimum DC input voltage. This sets the duty cycle (D).
   - $V_{in_{min}} = V_{AC_{min}}\sqrt{2} - 20 \text{ (V)}$
   - $V_{fl} = V_{min}$
2. Calculate the duty cycle which is 50% or less for the discontinuous mode flyback.
   - $D_{max} = \dfrac{V_{fl}}{V_{in_{min}} + V_{fl}}$
3. Calculate the peak device current (I_{pk}). There may be a switching device limit (for example VIPer53DIP-E has a current limit of 1.7 A).
   - $I_{pk} = \dfrac{2P_{o_{max}}}{\eta \bullet V_{in_{min}} \bullet D_{max}}$
4. Calculate the primary inductance (L_p). This is the inductance used for the current in the switching device to reach the peak current during the duty cycle.
   - $L_P = \dfrac{V_{in_{min}} \bullet D_{max}}{I_{pK} \bullet f}$

5. Calculate the primary turns (N_P):

– $$N_P = \sqrt{\frac{G_{in} 25.4 \bullet L_P}{A_e 4\pi 10^{-8}}}$$

6. Calculate the secondary turns (Ns) and auxiliary turns (N_{aux}):
   – $N_s = N_p (V_o + V_{do}) / V_{fl}$
   – $N_{aux} = N_p (V_{aux} + V_{da}) / V_{fl}$
7. Calculate the maximum flux density (Bm, Gauss), which depends on the core material.
   – $B_m = L_p I_{pk} 10^8 / N_p A_e$

Flyback transformers vary in size and shape, but the most common is an E-E type core with a gap in the center leg. It is basically an inductor where the energy is stored in the center leg (note the polarity of the transformer windings). The cores have an effective core area (A_e) which can be estimated for a transformer design. A gap is selected and then other values are calculated. If the resulting parameters are not reasonable, another core can be selected with an A_e which works better with the application. The bobbin area for the selected core is also difficult to estimate because it is the result of all previous calculations, wire size, number of turns and safety requirements such as creepage and clearance, and bobbin pin spacing. A core size starting points for the following devices are: VIPer12ADIP-E - 16 mm, VIPer22ADIP-E - 20 mm, and VIPer53DIP-E - 25 mm.

Reasonable results include $D_{max} \leq 50\%$, I_{pk} < a specified limit, a gap between 0.005 and 0.03 in., B_{max} < X000 Gauss (depends on core material), meets safety spacing requirements, does not run too hot and fits on the bobbin/core.

1.3 What if

If the wire does not fit:

1. Choose a somewhat smaller gap which decreases the turns (check the flux density)
2. Increase the operating frequency, which decreases the number of turns and the flux density.
3. Reduce the flyback voltage, which increases the peak current (check the limit), reduce the primary inductance and reduce the number of turns (the flux density will be the same).
4. Select a larger bobbin/core.

- The flux density is too high:

1. The gap can be increased somewhat which also increases the number of primary turns (check the size).
2. Increase the operating frequency, which decreases the number of turns and the flux density.
3. A larger core with a larger effective core area (A_e) can be used.

- The peak current is too high:

1. Use a device with a higher peak limit.
2. Check that the duty cycle is up to 50%.

Section 1.4 is a spreadsheet, containing the above equations, which can be used for calculations. *Section 1.5* is a Mathcad version. The minimum DC voltage used is 100 V from the minimum input voltage of $85V_{AC}$.

1.4 Transformer design equations:

- For a VIPer53DIP-E, 1.7A I_{pk} limit:
  - $V_{in_{min}} = 100V$; $V_{fl} = 100V$; $P_{o_{max}} = 35W$; $\eta = 0.85$; f = 100 kHz
  - $D_{max} = 0.50$ (50% max); $I_{pk} = 1.65$ A (Less than I_{pk} limit); $L_p = 304$ µH (from D_{max}, I_{pk})
  - $A_e = 0.315$ (From core selection)
  - $G_{in} = 0.015$ (G_{in} range 0.010 to 0.020in., 0.005min, 0.030max)
  - $V_o = 22.50$ V; $V_{do} = 0.70$ V; $V_{aux} = 15$V; $V_{da} = 0.60$ V
  - $N_p = 54.1$; $N_s = 12.5$
  - $N_{aux} = 8.4$;
  - $B_{max} = 2936$

1.5 Flyback transformer equations:

- For VIPer53DIP-E, 1.7A I_{pk} limit
  - $V_{in_{min}} = 100V$; pick $V_{fl} = 100$ V; $P_{o_{max}} = 35W$; $\eta = 0.85$; pick $f = 100 \bullet 10^3$

Equation 1

$$D_{max} = \frac{V_{fl}}{V_{in_{min}} + V_{fl}} \qquad D_{max}=0.5$$

maximum 50%

Equation 2

$$I_{pk} = \frac{2 \bullet P_{o_{max}}}{\eta \bullet V_{in_{min}} \bullet D_{max}} \qquad I_{pk}=1.65$$

I_{pk} less than switching device limit

Equation 3

$$L_p = \frac{V_{in_{min}} \bullet D_{max}}{I_{pk} \bullet f} \qquad L_P = 3.04 \bullet 10^{-4}$$

from D_{max}, I_{pk}

- For an EF20 core; A_e=0.315; choose A_e=0.315
  - Choose G_{in}=0.015; 0.010 to 0.020in; min 0.005; max 0.030in
  - V_o=22.5 V; V_{do}=0.70 V; V_{aux}=15 V; V_{da}=0.60 V

- For primary turns:

Equation 4

$$N_p = \sqrt{\frac{G_{in} \bullet 25.4 \bullet L_p}{A_e \bullet 4 \bullet \pi \bullet 10^{-8}}} \qquad N_p=54.1$$

- For secondary turns:

Equation 5

$$N_s = \frac{N_p \bullet (V_o + V_{do})}{V_{fl}} \qquad N_s=12.5$$

- For auxiliary turns:

Equation 6

$$N_{aux} = \frac{N_p \bullet (V_{aux} + V_{da})}{V_{fl}} \qquad N_{aux}=8.4$$

- For maximum flux density:

Equation 7

$$B_m = \frac{L_p \bullet I_{pk} \bullet 10^8}{N_p \bullet A_e} \qquad L_{p_{Bm}} = 2.94 \bullet 10^{-3}$$

2 Revision history

Table 1. Revision history

Date	Revision	Changes
18-Jan-2007	1	First issue