Flyback Transformer Calculations

This is the Flyback Calculator work sheet. It is for the analysis of a Flyback Design operating Qr Mode Items in yellow are values that need/can be changed

V1.0 Initial Releas
V1.1 Updated Wire selection

Input Data

Key Output Data

Authors:
A. Brinlee

Electrical Parameters

$Vacmin := 90\ V$	**VrmsMinimum AC Input Voltage**
$Vacmax := 264\ V$	**Vrms Maximum AC Input Voltage**
$FacMainsMin := 47\ Hz$	**Minimum AC Mains Frequency**
$Vbrfd := 0.9\ V$	**Bridge Rectifier forward voltage drop**
$Vpkmin := Vacmin \cdot \sqrt{2} = 127.2792\ V$	**Peak Rectified voltage at the Vac min point**
$Vpkmax := Vacmax \cdot \sqrt{2} = 373.3524\ V$	**Peak Rectified voltage at the Vac max point**
$Vo1 := 12\ V$	**Output Voltage**
$Io1 := 1.75\ A$	**Output Current**
$Vfd1 := 0.45\ V$	**Forward Voltage drop of the output rectifier**
$Vo2 := 14\ V$	**Output Voltage**
$Io2 := 0.1\ A$	**Output Current**
$Vfd2 := 0.9\ V$	**Forward Voltage drop of the output rectifier**
$Cbulk := 68\ \mu F$	**Nominal input bulk capacitance**
$TolCbulk := 20\ \%$	**Bulk Cap Tolerance**
$thold := 4\ ms$	**Minimum Holdup requirements**
$\tan\delta := 0.24$	**Tan Delta of the Bulk Capacitor**
$Vbrownout := 68\ V$	**Bulk Cap DC Voltage the brownout protection circuit trips in**
$\eta := 88\ \%$	**Expected PSU efficiency**
$Dmax := 0.45$	**Maximum Dudty Cycle**
$Vacnom := 115\ V$	**Nominl AC Line voltage to consider the holdup time with**
$Fsw := 45\ kHz$	**Switching Frequency**
$LeakagePercent := 1.2\ \%$	**Target ratio of Leakage Inductance to Primary Inductance**

$Kcoupling := \sqrt{1 - LeakagePercent}$ **Transformer Coupling Factor**

$Kcoupling = 0.994$

$Po := Vo1 \cdot Io1 + Vo2 \cdot Io2 = 22.4\ W$ **Output Power**

$Pin := \frac{Po}{\eta} = 25.4545\ W$ **Estimated Input Power**

Core Parameters PQ26/20 A-Core JPP-44

$Ac := 119\ mm^2$ **Core cross sectional winding area**

$MPL := 46.3\ mm$ **Magnetic Path Length from core data sheet**

$MLT := 56.55\ mm$ **Mean Length per Turn from bobbin data sheet**

$Volfe := 5509.7\ mm^3$ **Core Fe Volume**

$CoreWid := 19\ mm$ **Core Width**

$CoreLen := 26.5\ mm$ **Core Length**

$CoreHt := 20.15\ mm$ **Core Height**

$WindowWidth := 11.5\ mm$ **Winding Window Width**

$WindowHt := 5.25\ mm$ **Window Winding Height (B-jC)/2**

$\mu := 2400$ **Core Permeability**

Window Area

$Wa := WindowWidth \cdot WindowHt$

$Wa = 0.6038\ cm^2$

$BobbinWidth := WindowWidth - 2.2\ mm$
$BobbinWidth = 0.93\ cm$
$BobbinWidth = 8.03\ mm$ Measured

Use this equation or enter from bobbin mfg data sheet. Use 2.2mm when using tripple insulated wire and 8.2mm when using margin tape.

$Ap := Wa \cdot Ac$ Power Handling ability of the core

$Ap = 0.7185\ cm^4$

$At := 2 \cdot CoreLen \cdot CoreWid + 2 \cdot CoreLen \cdot CoreHt + 2 \cdot CoreWid \cdot CoreHt$

$At = 28.4065\ cm^2$

Surface Area for heat dissipation
For EE/ER style transformers use the above but substitute for Core Height the following: CoreHt+2*WindowHt

Constants

$Ki := 0.0388$ Gap Loss Coefficient

$Ku := 0.32$ Window utilization factor use 40% for most cases

$Kf := 4$ Waveform coefficient use 4 for a square wave or 4.4 for a sinewave

Bulk Capacitor Calculations

$$Cbulkmin := \frac{2 \cdot Pin \cdot thold}{(Vpkmin - 2 \cdot Vbrfd)^2 - (90\ V)^2} = 26.6364\ \mu F$$

Choose CBulk > than this value

90V is the expected min Bulk Cap Voltage-Will be calculated Later

$D_{LC} := 0.2$ Bulk Cap conduction Dutycycle

$$Cesr := \frac{\tan\delta}{2 \cdot \pi \cdot 2 \cdot FacMainsMin \cdot Cbulk \cdot (1 - TolCbulk)}$$

$Cesr = 7.4697\ \Omega$

$$VBulkMin := \sqrt{2 \cdot Vacmin^2 - \frac{Pin \cdot (1 - D_{LC})}{Cbulk \cdot FacMainsMin}} = 99.1383\ V$$

$VBulkMin := 90\ V$ Choose VBulkMin < that Voltage Above

$VacNomPk := Vacnom \cdot \sqrt{2} - 2 \cdot Vbrfd = 160.8346\ V$

$$Vref1 := \frac{Dmax \cdot VBulkMin}{(1 - Dmax)} = 73.6364\ V$$

Reflected voltage on the primary

$VBulkPk := Vpkmax - 2 \cdot Vbrfd = 371.5524\ V$ Peak Voltage on the Bulk cap

$Vdsref := VBulkPk + Vref1 = 445.1887\ V$

Peak Plateau voltage seen by the FET
Does not include the leakage inductance spike

Transformer Design

$\Delta\beta m := 2700\ G$ Peak Flux Density in Tesla

$$n := \frac{Vref1}{Vo1 + Vfd1} = 5.9146$$

Turns ratio

$$Vrr_{opd} := \frac{VBulkPk}{n} + Vo1 + Vfd1 = 75.2699\ V$$

Reverse Recovery on the output rectifier

$$Ipk := \frac{Pin}{VBulkMin \cdot Dmax} \cdot 2 = 1.257\ A$$

Peak Current during the swithch On time

$$Lp := \frac{VBulkMin \cdot Dmax}{Ipk \cdot Fsw} = 715.9821\ \mu H$$

Required Inductance

$$Ispk := \frac{Po}{Vo1 \cdot (1 - Dmax)} = 3.3939\ A$$

Secondary Side peak current

$$Np := round\left(\frac{Ipk \cdot Lp}{\Delta\beta m \cdot Ac}, 0\right) = 28$$

Adjust Dl and Dbm above to get a whole number

$$Ns1 := round\left(\frac{Np}{n}, 0\right) = 5$$

Number of Secondary turns

$lg := 0.1569\ mm$ **Adjust lg (Core Gap) until Lgapped = Lp**

$$FFlux := 1 + \frac{lg}{\sqrt{Ac}} \cdot \ln\left(\frac{2 \cdot WindowWidth}{lg}\right) = 1.0717$$

Fringing Flux Caused by gapping the core

$$Lgapped := \frac{\left(0.4 \frac{H}{m} \cdot \pi \cdot 10^{-6}\right) \cdot Np^2 \cdot FFlux \cdot Ac}{lg + \frac{MPL}{\mu}}$$

$Lgapped = 713.1417\ \mu H$ This needs to equal Lp $Lp = 715.9821\ \mu H$

$$Bmax := \frac{0.4 \frac{H}{m} \cdot \pi \cdot Np \cdot FFlux \cdot (Ipk) \cdot 10^{-6}}{lg + \frac{MPL}{\mu}} = 2690.3648\ G$$

Double Check this against your input requirement

$Energy := \frac{Lp \cdot Ipk^{2}}{2}$ Energy in W-S

$Energy = 0.0006\ J$ Available energy storage in the gap

$Energy \cdot Fsw = 25.4545\ W$ Max Power available at that frequency and inductance

$ALe := \frac{Lp}{Np^{2}} = 0.9132\ \mu H$ Effective ALe gapped uH/turn

$H := \frac{0.4 \cdot \pi \cdot Np \cdot Ipk}{MPL} = 12.0043\ Oe$ Oersteds Check this against data sheet curves

$Pg := Ki \frac{10^{4}\ W}{\left(m^{2}\ T^{2}\right) Hz} \cdot WindowWidth \cdot lg \cdot Fsw \cdot \Delta\beta m^{2}$ McLyman - Transformer and Inductor design Handbook

$Pg = 2.2966\ W$

$Ns2 := round\left(\frac{Vo2 + Vfd2}{Vo1 + Vfd1} \cdot Ns1 , 0\right) = 6$ Number of Aux turns

$Vo2Actual := \frac{Ns2}{Ns1} \cdot \left(Vo1 + Vfd1\right) - Vfd2 = 14.04\ V$

Skin Depth and Wire Selection

$\rho := 1.7241 \cdot 10^{-6}\ \Omega\ cm$ Nema M1000 pdf

$\alpha := 0.0039$ Temperature Compensation for Cu

$TempW := 100$ Degree C Operating Wire temperature

$Tambient := 20$ Ambient Wire Temperature the Cu constant was derived from

$\rho e := \rho \cdot \left(1 + \alpha \cdot \left(TempW - Tambient\right)\right)$

$\rho e = 2.262 \cdot 10^{-6}\ \Omega\ cm$ Adjusted electrical Resistivity

$Kcu := \sqrt{\frac{\rho e}{\rho}}$

$\delta := \frac{6.62}{\sqrt{Fsw}} \cdot Kcu \cdot \sqrt{Hz}\ cm$

$\delta = 0.0357\ cm$ Skin Depth in cm

$MaxWireDia := 2 \cdot \delta$

$MaxWireDia = 0.7149\ mm$ Maximum wire Diameter that uses 100% of the Cu area at the fundamental switching frequency

Primary Wire Selection

$W_p := 0.32\ mm$ Furikawa TEX-E 0.32mm or Rubadue 28AWG Tripple Insulated

$W_{priOD} := 0.54\ mm$ OD with Insulation

Target is Low Leakange and innerwinding C on the primary so use a
Split winding for the primary and sandwith the secondary between them.

$$Pri_{windingfit} := \frac{BobbinWidth}{W_{priOD}} = 14.8704$$ this should be < Np/2 for a split winding

$$I_{priRMS} := Ipk \cdot \sqrt{\frac{Dmax}{3}} = 0.4868\ A$$ Primary Side RMS current

$$R_{pdc} := \frac{\rho e \cdot MLT \cdot Np}{\left(\frac{W_p}{2}\right)^2 \cdot \pi} = 0.4453\ \Omega$$ Power Dissipation at 100C

$$P_{priwire} := {I_{priRMS}}^2 \cdot R_{pdc} = 0.1056\ W$$

Secondary Side Wire Selection

$W_s := 0.1\ mm$ Litz Wire

$Strands_{sec} := 100$ Uses 100x0.1mm Stranded Litz Wire

$$W_{secarea} := \left(\frac{W_s}{2}\right)^2 \cdot Strands_{sec} \cdot \pi = 0.7854\ mm^2$$

$Litz_{od} := 0.125\ mm$

$$Wire_{bundleod} := 2 \cdot \sqrt{\left(\frac{Litz_{od}}{2}\right)^2 \cdot Strands_{sec}} = 1.25\ mm$$

$$Sec_{windingfit} := \frac{BobbinWidth}{Wire_{bundleod}} = 6.424$$ Must be < than Ns1

$$Isec_{pk} := \frac{Io1 \cdot 2}{(1 - Dmax)} = 6.3636\ A$$ Assumes QR mode and disregars time for the transformer winding dead time between cycles as the winding rings to the next state.

$$I_{secRMS} := Isec_{pk} \cdot \sqrt{\frac{(1 - Dmax)}{3}} = 2.7247\ A$$ RMS Current through the coil

$$R_{sdc} := \frac{\rho e \cdot MLT \cdot Ns1}{W_{secarea}} = 0.0081\ \Omega$$

$$P_{secwire} := {I_{secRMS}}^2 \cdot R_{sdc} = 0.0605\ W$$

Auxillary Winding Selection

$W_{ns2} := 0.25\ mm$ Auxillary Wire Se;ection TEX-E Furikawa

$W_{ns2maxOD} := 0.467\ mm$

$$W_{vertfit} := W_{ns2maxOD} + Wire_{bundleod} + 2 \cdot W_{priOD} = 2.797\ mm$$ Adjust Wvertfit< BobbinHeght