Dimensionnement d'une alimentation à découpage Forward

SALVETTI Djoumé

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2 Rappels sur l'alimentation FORWARD

$$V_s = \alpha m E \tag{1}$$

$$\alpha \leq \frac{n_1}{n_1 + n_3} \tag{2}$$

3 Dimensionnement

Note : sauf indication contraire, et dans le but de simplifier les calculs, on négligera le courant magnétisant ainsi que l'ondulation du courant de sortie pour dimensionner les différents éléments de l'alimentation.

Le principe de l'alimentation forward fait que le transfert d'énergie entre la source (E) et la charge n'a lieu que pendant la première période de fonctionnement ($0 \leq t \leq \alpha T$), on va donc chercher a faire durer le plus longtemps possible cette période en prennant α le plus grand possible.

Mais il faut absolument respecter la *condition de démagnétisation* du transformateur (2), ce qui conduit à choisir n_3 d'autant plus petit que α est grand.

D'autre part, le transistor T1 est soumis à une tension égale à $E(1 + \frac{n_1}{n_3})$ lorsqu'il est ouvert. Cette tension (qui est d'autant plus grande que n_3 est petit) est un élément dimensionnant du transistor que nous devons également chercher à la minimiser.

On voit donc qu'il y a un compromis à faire entre une bonne utilisation de l'alimentation et la limitation de la tension aux bornes du transistor.

Si l'on souhaite limiter la tension aux bornes du transistor à 2E il faut choisir :

$$n_1 = n_3 \tag{3}$$

(2) devient alors

$$\boxed{\alpha \leq \frac{1}{2}} \tag{4}$$

3.1 Le transformateur

3.1.1 Rapport de transformation

Différentes imperfections des éléments de notre alimentation vont faire chuter la tension de sortie lors de sa réalisation pratique (tension de seuil des diodes, résistances des bobinages, ...).

Afin de conserver une marge de manoeuvre dans le cas ou ces imperfections nous empêcheraient de respecter la cahier des charges, nous allons calculer le rapport de transformation de façon à ce que la tension théorique de sortie soit de 15V pour un rapport cyclique de 0,4 (de cette façon il sera toujours possible d'augmenter le rapport cyclique jusqu'à 0,5 si besoin est).

A partir de (1) nous calculons :

$$\boxed{m = \frac{V_s}{\alpha E} = 0,75} \tag{5}$$

3.1.2 Choix du pot

A partir de l'équation de Faraday et en supposant l'induction constante a travers une section du circuit magnétique on obtient :

$$A_e = \frac{E}{2fn_1B_{max}} \tag{6}$$

D'autre part :

$$i_{1eff} = m\sqrt{\alpha}I_s = mi_{2eff}$$

On peut alors calculer la section des conducteurs des spires (s_1, s_2) en fonction de la densité de courant (J) :

$$s_1 = \frac{i_{1eff}}{J} = m\sqrt{\alpha}\frac{I_s}{J}$$

$$s_2 = \frac{\sqrt{\alpha}}{J}I_s$$

Pour essayer de minimiser l'inductance de fuite entre les enroulements 1 et 3 nous allons utiliser le même fil $(s_1 = s_3)$ pour les deux enroulements et les bobiner en même temps (méthode appelée "deux fils, une main"). Si l'on considère un coefficient de bobinage k_f nous pouvons exprimer la surface de cuivre nécessaire :

$$S_{cu} = k_f(n_1s_1 + n_2s_2 + n_3s_3) = \frac{3k_fmn_1\sqrt{\alpha}I_s}{J}$$

En remplaçant α par 0,5[1] on obtient :

$$S_{cu} = \frac{1,6k_fn_1I_s}{J} \tag{7}$$

Il faut un pot où S_b (section bobinable) est supérieure à S_{cu}.

A partir de (6) et (7) nous pouvons exprimer la condition sur le "produit des aires" :

$$\boxed{A_eS_b \geq 0,79\frac{k_fEI_s}{JfB_{max}}} \tag{8}$$

On se fixe : $\boxed{f = 50kHz}$ et $\boxed{\text{2W de pertes fer}}$ pour pouvoir dimensionner le transformateur.

Le flux dans le transformateur étant unidirectionnel,les pertes associées seront plus faible qu'en régime sinusoidal. Le rapport entre la valeur efficace du courant primaire du transformateur et la valeur efficace d'un courant sinusoidal étant de 80%, nous utiliserons ce coefficient pour estimer les pertes que l'on aurait dans le transformateur en régime sinusoidal.

On estime donc que 2W de pertes fer avec notre excitation correspondent à 2,5W de pertes dans le transformateur s'il était soumis à une excitation sinusoidale.

Pour réaliser notre transformateur nous disposons de matériau ferrite de type FERRINOX B52 et de ses caractéristiques (page 5) :

Nous voyons donc qu'avec une fréquence de 50 kHz, il ne faut pas que l'induction maximale dépasse 200 mT si l'on veut avoir des pertes inférieures à 2,5W.

On prendra donc : $\boxed{B_{max} = 0,2T}$

On optimisera le rendement du transformateur en égalisant les pertes joules et les pertes fer, ce qui impose : $\boxed{J = 4A/mm^2}$

De plus on considèrera $\boxed{k_f = 2,5}$ ce qui est une valeur communément admise pour un bobinage manuel.

Nous pouvons maitenant estimer le produit des aires :

$$A_eS_b = 9,84.10^3mm^4$$

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[1] On dimensionne le transformateur de façon à pouvoir augmenter α jusqu'à 0,5.

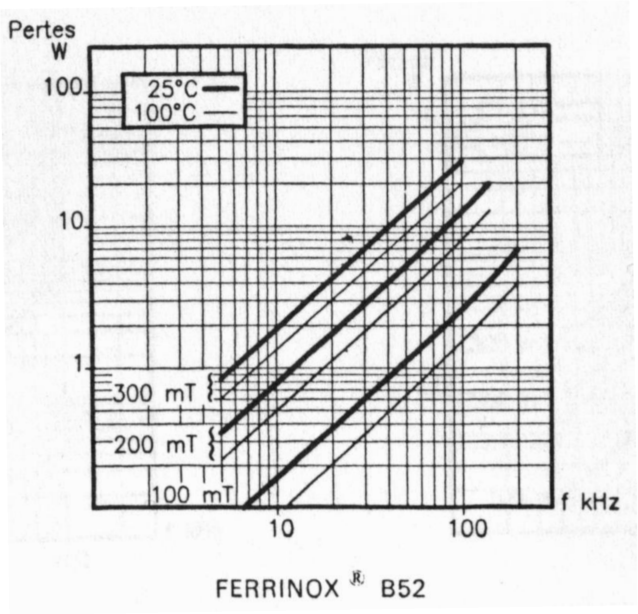

FIG. 1 – Pertes fer en fonction de la fréquence

Ceci nous permet de faire le choix entre les 2 types de pots dont nous disposons :

Type de pot	$A_e(mm^2)$	$S_b(mm^2)$	$A_eS_b(mm^2)$
RM14	190	106	20140
RM10	95	42	3990

Seul un pot de type RM14 peut convenir.

3.1.3 Calcul des conducteurs

Une fois ce choix fait, nous pouvons calculer à partir de (6) les nombres de spires primaires et secondaires :

$$\boxed{n_1 = n_3 = 13} \qquad ; \qquad \boxed{n_2 = 10} \tag{9}$$

Ainsi que les surfaces des conducteurs :

$$s_1 = 0,53mm^2 \qquad ; \qquad s_2 = 0,71mm^2$$

L'épaisseur de peau à 50 kHz est de :

$$\delta = \frac{2}{\sigma\omega\mu} = 0,29mm$$

Nous pouvons donc utiliser du fil de section 0,5 mm, ce qui impose d'utiliser k_1 conducteurs par spire au primaire et k_2 au secondaire, avec :

$$k_1 = \frac{0,53}{0,25^2\pi} = 2,7 \implies \boxed{k_1 = 3}$$
$$k_2 = \frac{0,71}{0,25^2\pi} = 3,61 \implies \boxed{k_2 = 4}$$

3.2 L'inductance de lissage

Le cahier des charges étant insufisant pour permettre le dimmensionnement de l'inductance de lissage, nous nous fixerons une ondulation maximale du courant.

On prendra $\boxed{\Delta I_s \leq 0,4A}$ afin d'être sur d'être en conduction continue pour un courant de sortie supérieur à 0,4 A.

De plus nous ferons nos calcul dans le cas le plus défavorable ($\alpha = 0,5$).

$$L = \frac{mE}{4f\Delta i} \implies \boxed{L = 62,5\mu H}$$

$$\Phi tot_{max} = LI_{max} = nB_{max}A_e \implies A_e = \frac{LI_{max}}{nB_{max}}$$

$$s = \frac{I_{eff}}{J} \implies S_b \geq k_f n \frac{I_{eff}}{J}$$

$$A_e S_b \geq \frac{LI_{max}I_{eff}k_f}{B_{max}J}$$

On néglige l'ondulation de courant donc on peut confondre I_{max} et I_{eff} :

$$\boxed{A_e S_b \geq \frac{LI_{max}^2 k_f}{B_{max}J}} \qquad (10)$$

L'application numérique nous donne : $A_e S_b = 3,7810^3 mm^4$

Nous utiliserons donc un pot de type RM14.

Le théorème d'Ampère nous donne :

$$nI_{max} = \frac{B_{max}}{\mu_0}(e + \underbrace{\frac{l_e}{\mu_r}}_{\text{négligeable}})$$

Nous pouvons donc calculer l'épaisseur de l'entrefer nécessaire :

$$e = \frac{\mu_0 n I_{max}}{B_{max}} = \frac{n^2 A_e \mu_0}{L}$$

Cependant, dans notre cas nous ne disposons que d'entrefer de 0,5 mm ou 1 mm. Nous réglerons donc : $\boxed{e = 0,5mm}$ puis nous calculons le nombre de spire qui permettra d'obtenir l'inductance désirée :

$$n = \sqrt{\frac{Le}{A_e \mu_0}} \implies \boxed{n = 12} \tag{11}$$

Comme pour le transformateur, nous allons utiliser du fil de diamètre 0,5mm, il nous faudra donc $\boxed{k = 5}$ conducteurs par spire.

3.3 Le condensateur de sortie

En supposant que le courant dans la résistance est constant et égal à la valeur moyenne du courant i_L nous pouvons calculer l'ondulation de tension :

$$\Delta V_s = \frac{1}{C} \int_{\frac{\alpha T}{2}}^{\frac{T(\alpha+1)}{2}} i_c dt$$

D'oû :

$$\boxed{C \geq \frac{mE(1-\alpha)\alpha}{8\Delta V_s L f^2}} \tag{12}$$

L'application numérique nous donne : $\boxed{C = 150\mu F}$

Remarque : aux fréquences considérés (50 Hz) la plupart des condensateurs se comportent comme une résistance de faible valeur (voir documentations constructeur).

4 Mesure des paramètres du transformateur

Avant de faire fonctionner ensemble les différents éléments de notre alimentation, nous allons vérifier le bon fonctionnement de notre transformateur. Pour cela nous réaliserons le montage suivant :

Un essai en court circuit nous permet de mesurer l'inductance de fuite du transformateur :

$$\frac{E_g}{i_{eff}} = 2\pi l_f f$$

On mesure : $l_f = 14,3\mu H$

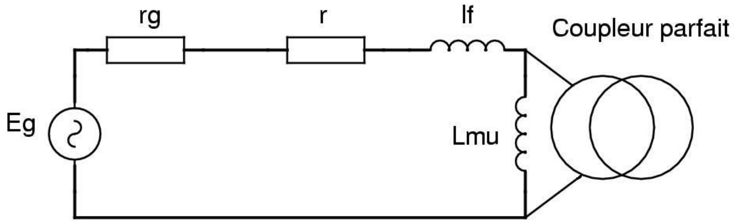

Fig. 2 – Mesure de l'inductance de fuite et de L_μ

Nous pouvons maintenant déterminer à partir d'un essai à vide l'inductance magnétisante :

$$\frac{E_g}{i_{eff}} = 2_p i(L_\mu + l_f)f$$

On mesure : $L_\mu = 976\mu H$

5 Réalisation d'un circuit écrêteur

L'inductance de fuite du transformateur va être à l'origine de surtensions aux bornes du transistor lors de son l'ouverture. Ces surtensions pouvant être destructrices, nous devons réaliser un circuit écrêteur.

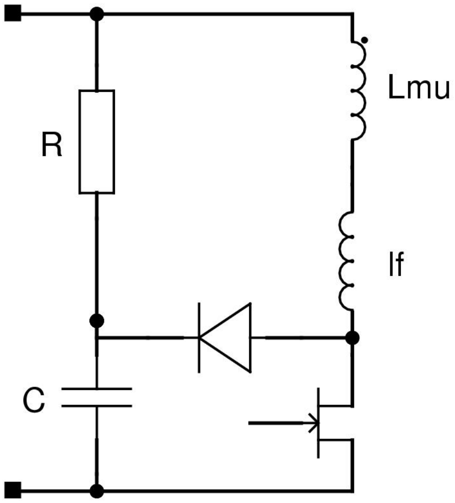

Fig. 3 – Mesure de l'inductance de fuite et de L_μ

L'idée est ici de dissiper l'énergie stockée dans l'inductance de fuite sous forme d'effet joule dans la résistance.

Pour dimensionner les différents éléments il suffit d'exprimer la puissance stockée dans l'inductance de fuite :

$$P = \frac{1}{2} l_f i^2 f = \frac{(V_0 - E)^2}{R}$$

On se fixe alors une tension V_0 a ne pas dépasser en fonction du calibre du transistor (par exemple $V_0 = 150V$ dans le cas de l'IRF 640), ceci nous permet de calculer R. Il faut que la tension aux bornes du condensateur reste constante pendant l'ouverture du transistor, ceci se traduit par l'équation :

$$fRC \gg 1$$

Nous pouvons alors calculer la valeur minimum à donner à C.

Pour notre application nous avons choisi $\boxed{R = 1k\Omega}$ et $\boxed{C = 200nF}$.

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