Optimal design of iron core section of power transformer based on Comsol

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Abstract

The filling coefficient will enhance and which means that the effect of space utilization is well and magnetic leakage is less. Putting hand to calculate from the open circuit losses. In order to save time, we own special requirement for the open circuit losses, which could figure out iron core diameter D rapidly and save the cost. The series of iron core should be selected appropriately in a range. Basically, with the increase of diameter, the series enhance too. We usually use table look-up to determine the series of iron core.

Keywords

Power transformer; electromagnetic theoretical formula, optimal design.

1. Generally method of iron core section selection

Majority of transformers adopt Iron core column with Multistage rectangular cross section formed by circumcircle stacked by steel silicon wafer in order to let magnetic evenly distributed and simplify the process.

It could be obviously discovered that the section of multistage rectangle increasingly verges on circle if the series are more. The numerical value that geometric area of multistage rectangle divided by circular area called filling coefficient of iron core.

If we only pursuit more iron core series, the filling coefficient will enhance and which means that the effect of space utilization is well and magnetic leakage is less. But with the growth of series, the process difficulty of punching shear and stacking for iron core and manufacturing time all increase drastically. So, the series of iron core should be selected appropriately in a range. Basically, with the increase of diameter, the series enhance too. We usually use table look-up to determine the series of iron core

2. Optimization analysis of iron core section

Due to electromagnetic theoretical formula : $U=4.44fNBS$, we could obtain the following conclusions : when U, F don't change, NBS is a fixed constant . So we can infer :

(1) If we determine the number of turns of the coil N and increase the sectional area of iron core, which can decrease the density of magnetic flux B passed through iron core. In this way, it could decrease the open circuit losses to a certain extent;

(2) If the density of magnetic flux B we select is constant and increase the sectional area of iron core S as much as possible, which could decrease the number of turns of the coil. It could not only save materials, but also reduce the load losses of power transformer.

When the geometric sectional area of iron core is maximum, we consider about

the pros and cons of maximum geometric area of iron core column through space filling coefficient of iron core. In summary, we establish a Nonlinear Integer Programming according to the requirements. The concrete models are as follows:

$$\max S = \beta \cdot \sum_{i=1}^{n} L_i \cdot W_i \quad \text{s.t. } L_i = 5 \cdot x, (x \in N) \tag{1}$$

$$W_1 > W \tag{2}$$

$$L_i > L_{i+1} \qquad i = 1,2.3,\ldots\ldots,n-1 \tag{3}$$

$$L_{14} \geq L \tag{4}$$

$$i=2,3,\ldots\ldots,n \tag{5}$$

$$R_i \leq R \qquad i = 1,2.3,\ldots\ldots,n \tag{6}$$

Among the models, D_i, W_i, L_i, R_i are unknown quantities, W=26mm, L=20mm, R=325mm, we select β as 0.970, formula (1) guarantees that the width of each series is a multiplier of 5mm, formula (2) guarantees that first series thickness of iron core column section greater than 26mm, formula (3) guarantees that the thickness of each series step increases from up to down, formula (4) guarantees that the thickness of each width is equal or greater than 20mm, formula (5) and (6) guarantees that the size of designed iron core column doesn't exceed the range of circumcircle.

3. Model Establishment in comsol

Opening Comsol software and selecting establish new model. Selecting Physical

Field as Math-Optimization. Inputting W in parameter and setting up the numerical value as 26. Inputting L in parameter and setting up the numerical value as 20. Inputting R in parameter and setting up the numerical value as 325. According to above constraint condition, for example, n=12, inputting successively L1, L2, L3, L4, L5, L6, L7, L8, L9, L10, L11, L12, L13, L14, W1, W2, W3, W4, W5, W6, W7, W8, W9, W10, W11, W12 in parameter. Because Li is integer multiple of 5, we separately assign as 15, 14, 13, 12, 11, 10, 9, 8, 7, 6, 5, 4, 26, 26, 26, 26, 26, 26, 26, 26, 26, 26, 26, 26 for above 24 parameters.

设置
参数

参数

名称	表达式	值	描述
l1	15	15	
w1	26	26	
l2	14	14	
w2	26	26	
l3	13	13	
l4	12	12	
l5	11	11	
l6	10	10	
l7	9	9	
l8	8	8	
l9	7	7	
l10	6	6	
l11	5	5	
l12	4	4	
w3	26	26	
w4	26	26	
w5	26	26	
w6	26	26	
w7	26	26	
w8	26	26	
w9	26	26	
w10	26	26	
w11	26	26	

Chart1 Parameter setting

Then selecting Addition research. Adding the following expression in optimal objective function

5* W1*floor（L1）

5* W2*floor（L2）

5* W3*floor（L3）

5* W4*floor（L4）

5* W5*floor（L5）

5* W6*floor（L6）

5* W7*floor（L7）

5* W8*floor（L8）

5* W9*floor（L9）

5* W10*floor（L10）

5* W11*floor（L11）

5* W12*floor（L12）

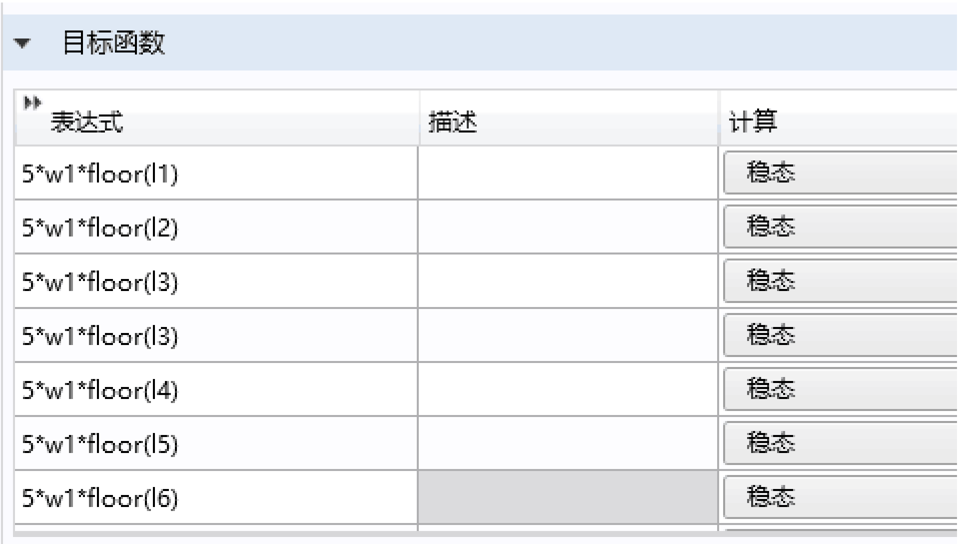


Chart2 Target function setting

Selecting Maximization in type, total target in multiple target.

Adding the parameter set up before in control variable and parameter.

In constraint, inputting：

325>sqrt(l12*l12/4+(1/2*w1+w2+w3+w4+w5+w6+w7+w8+w9+w10+w11+w12)*(1/2*w1+w2+w3+w4+w5+w6+w7+w8+w9+w10+w11+w12))

325>sqrt(l11*l11/4+(1/2*w1+w2+w3+w4+w5+w6+w7+w8+w9+w10+w11)*(1/2*w1+w2+w3+w4+w5+w6+w7+w8+w9+w10+w11))

325>sqrt(l10*l10/4+(1/2*w1+w2+w3+w4+w5+w6+w7+w8+w9+w10)*(1/2*w1+w2+w3+w4+w5+w6+w7+w8+w9+w10))

325>sqrt(l9*l9/4+(1/2*w1+w2+w3+w4+w5+w6+w7+w8+w9)*(1/2*w1+w2+w3+w4+w5+w6+w7+w8+w9))

325>sqrt(l8*l8/4+(1/2*w1+w2+w3+w4+w5+w6+w7+w8)*(1/2*w1+w2+w3+w4+w5+w6+w7+w8))

325>sqrt(l7*l7/4+(1/2*w1+w2+w3+w4+w5+w6+w7)*(1/2*w1+w2+w3+w4+w5+w6+w7))

325>sqrt(l6*l6/4+(1/2*w1+w2+w3+w4+w5+w6)*(1/2*w1+w2+w3+w4+w5+w6))

325>sqrt(l5*l5/4+(1/2*w1+w2+w3+w4+w5)*(1/2*w1+w2+w3+w4+w5))

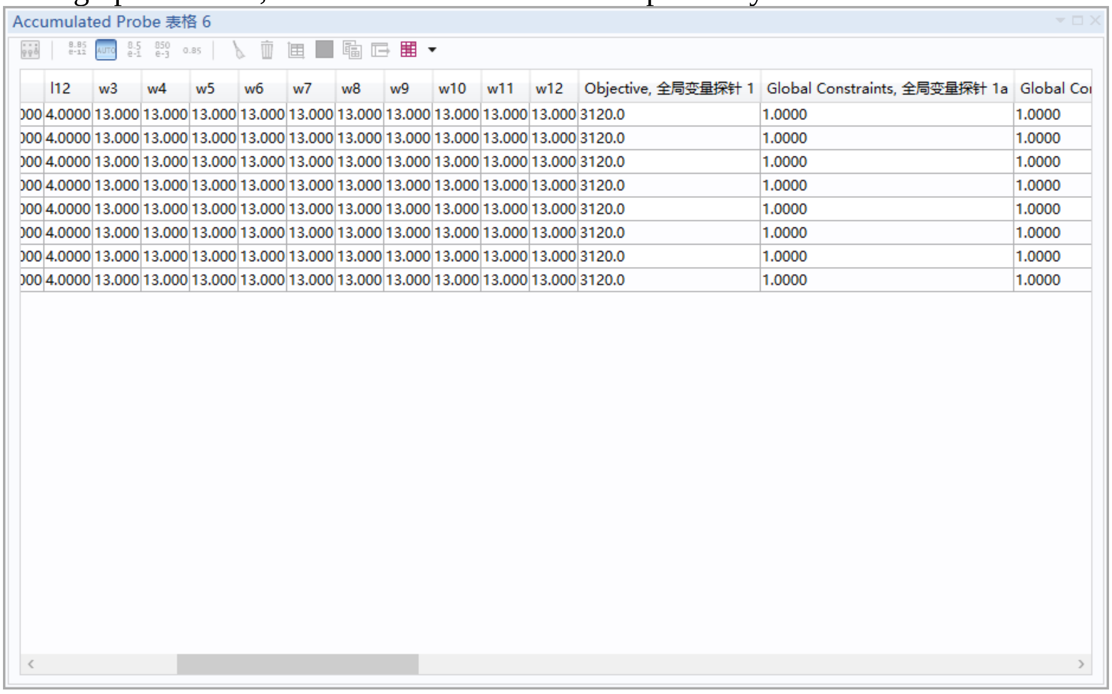
325>sqrt(l4*l4/4+(1/2*w1+w2+w3+w4)*(1/2*w1+w2+w3+w4))

325>sqrt(l3*l3/4+(1/2*w1+w2+w3)*(1/2*w1+w2+w3))
325>sqrt(l2*l2/4+(1/2*w1+w2)*(1/2*w1+w2))
325>sqrt(l1*l1/4+1/4*w1*w1)

表达式	下界	上界	计算
l12<l11<l10<l9<l8<l7<l...			稳态
325>sqrt(l12*l12/4+(w1...			稳态
325>sqrt(l11*l11/4+(w1...			稳态
325>sqrt(l10*l10/4+(w1...			稳态
325>sqrt(l9*l9/4+(w1+w...			稳态
325>sqrt(l8*l8/4+(w1+w...			稳态
325>sqrt(l7*l7/4+(w1+w...			稳态
325>sqrt(l6*l6/4+(w1+w...			稳态
325>sqrt(l5*l5/4+(w1+w...			稳态
325>sqrt(l4*l4/4+(w1+w...			稳态
325>sqrt(l3*l3/4+(w1+w...			稳态
325>sqrt(l2*l2/4+(w1+w...			稳态
325>sqrt(l1*l1/4+w1*w1)			稳态

Chart3 Constraint condition setting

Then clicking optimization, we could obtain the table outputted by comsol after calculation.



Accumulated Probe 表格 6

	l12	w3	w4	w5	w6	w7	w8	w9	w10	w11	w12	Objective, 全局变量探针 1	Global Constraints, 全局变量探针 1a	Global Co
000	4.0000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	3120.0	1.0000	1.0000
000	4.0000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	3120.0	1.0000	1.0000
000	4.0000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	3120.0	1.0000	1.0000
000	4.0000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	3120.0	1.0000	1.0000
000	4.0000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	3120.0	1.0000	1.0000
000	4.0000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	3120.0	1.0000	1.0000
000	4.0000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	3120.0	1.0000	1.0000
000	4.0000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000	3120.0	1.0000	1.0000

Chart4 manipulating data by computer

Then changing that n=12 and n=13. Repeated calculating after modifying the setting above and obtaining the result as the following table.

Chart12 relationship of Effective section area and filling coefficient

	Series n=12	Series n=13	Series n=14
Effective section area	319327	319924	320739
Filling coefficient	96.16%	94.46%	96.71%

When diameter of iron core D=650mm series is 12,n=12、13、14, filling coefficient as the following table:

Table2 The relationship of iron core series and filling coefficient

Series	1	2	3	4	5	6	7	8	9
Filling coefficient	0.637	0.787	0.851	0.886	0.908	0.923	0.934	0.942	0.953
Series	10	11	12	13	14	15			
Filling coefficient	0.953	0.955	0.958	0.961	0.967	0.969			

Table3 The relationship of iron core column series and iron core diameter

Iron core diameter D(mm)	80~90	96~120	125~195	200~225	230~240	245~265
Series n	6	6	7	8	9	10
Oil channels	-	-	-	-	-	-
Iron core diameter D(mm)	270~290	400~560	580~680	700~980	980以上	
Series n	11	12	13	14	15以上	
Oil channels	-	-	2	3	3以上	

Compared to the knowable, when it owns no oil channels and iron core diameter is 650mm, the filling coefficient of series n=14 is 96.71% maximally, increasing 0.36%

When n=14, stack is 27 series, filling coefficient increases 0.01%

When n=12, total stack is 23 series, 4 less than 14. Process difficulty and production time decrease more but filling coefficient enhances. The magnetic leakage of iron core compared reduces, decreasing the cost.

4. Conclusion

In actual design, we use Semi empirical formula method to figure out the diameter D just for reference. It needs multiple calculations and repeated optimal calculations for a obtaining most economic and satisfactory design in actual calculation.

Putting hand to calculate from the open circuit losses. In order to save time, we own special requirement for the open circuit losses, which could figure out iron core diameter D rapidly and save the cost.

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