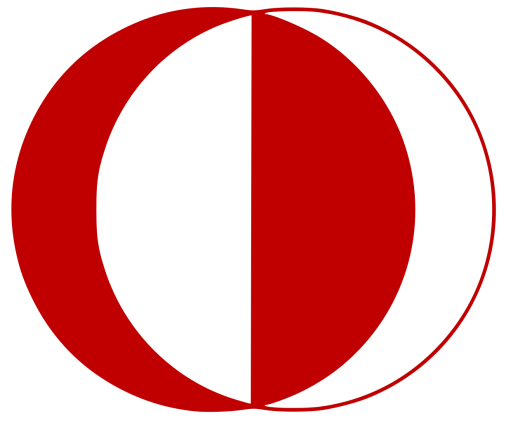
**EE564**

**DESIGN OF ELECTRICAL**

**MACHINES**

**2015/16 Spring Semester**

**Project #1**



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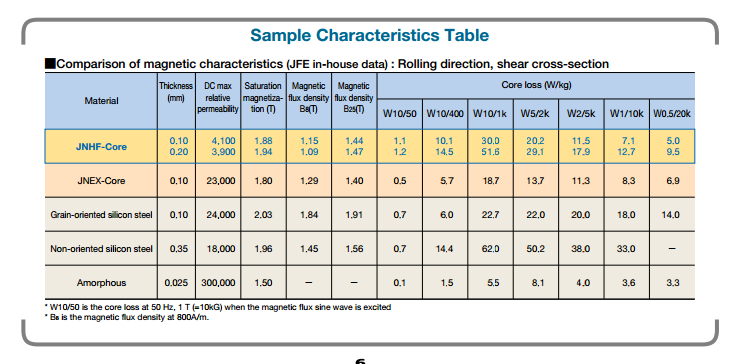
**Student Number : 1741719**

Project requirements:

* 6.5 MVA, Single Phase transformer
* Operating Frequency: 500 Hz
* Input Voltage: 3 kV
* Output Voltage: 300kV
* Operating Temperature 110 °C

**Selecting Core Material for 500hz application**

From JFE steel company website



Let’s assume operating Tesla vs loss stays linear until the saturation point.

There is no 500 Hz data readily available, so we need to curve fit the available data and determine and approximate loss value

Matlab code

x=[50,400,1000] %JNHF Core 0.1 mm at 1 Tesla

y=[1.1 , 10.1 , 30]

a=polyfit (x,y,2)

y=polyval(a,500)

x=[50,400,1000] %JNHF Core 0.2 mm at 1 Tesla

y=[1.2 , 14.5 , 51.6]

a=polyfit (x,y,2)

y=polyval(a,500)

x=[50,400,1000] %JNEX Core 0.1mm at 1 Tesla

y=[0.5 , 5.7 , 18.7]

a=polyfit (x,y,2)

y=polyval(a,500)

At 1 Tesla operating point

JNHF core 0.1 mm loss = 13.02 W/kg

JNHF core 0.2 mm loss =19.43 W/kg

JNEX core 0.1 mm loss = 7.5 W/kg

*Stacking factor at 0,9 for 0.1 mm*

*Stacking factor 0.92 for 0.2 mm*

*Selected core* ***JNEX***

*Properties:*

Density = 7,5 gr/cm^3

Thickness: 0,1 mm

Stacking Factor: 0,9

B-H : 800A/m for 1,29 tesla

Permeability=0,0016125

Loss: 7,5 W/kg for 500 hz 1 Tesla

**Insulation Calculation:**

Lv side is at 3 kV rms,

Hv side is at 300kV Rms

Oil impregnated Kraft paper breakdown voltage is around 40 kV/mm

Let’s select our insulation thickness 8kV/mm for hV side

And 10 kV/mm for lv side.

Reasoning:

\* The dielectric strength of the oil impregnated paper is not linear, the thicker the insulation easier it will breakdown (electric field distribution gets more nonlinear with the increased length).

\*Higher the stress on the insulating material, shorter the lifetime.

\*Although the system is isolated from environment, oil will get impure by the time and its insulating capability will reduce.

\* We should have at least 25 percent safety margin to pass the power frequency test, the insulation details are not given so 550 kV pf test is assumed.

550/300=1,84

40/1,84=21,74

Insulation will be thick, lets select use 0.6 constant

0.6\*21,74=13

Put a safety margin of 30 percent

13\*0,7=9,13.

Datasheet values will not be always met so let’s assume 10 percent deviation

9,13\*0,1=8,2=8kV/mm for hV side

For lV side insulation will be alot thinner so instead of 0.6 let’s use 0.9

8\*0.9/0.6= 12 kV/mm for lV side

Note: We are not operating with 50 hz but 500hz, so effective insulation will drop (around to 90-95 percent) but we already had enough safety factor so this change will be ignored.

These values can be optimized with simulation results and real tests.

**Selecting Copper dimensions and Insulation**

Primary current is 6.5m/3k =2167 A =2200 A (magnetizing current and core loss will drop this value)

We are operating at 500hz , to have almost 100 percent skin depth our maximum cable diameter can be 5.8 mm according to table which is about awg#3 but we are operating at 110 C so we need to recalculate the skin depth correcting the resistivity, which will yield around 6.6 mm , still it is safe to remain at awg #3

\delta=\sqrt{{2\rho }\over{\omega\mu}}.

P=1,3\*1,68\*10^-8

W=2\*3,14\*500

M=1,257\*10^-6

Result: 3.326\*10^-3 mm

Instead of using a standard cable, it is better to use copper stripes and insulate with oil impregnated Kraft paper . (Paper and oil datasheets have been uploaded at github).

*Primary*

Current density of primary: 3,5 A/mm^2

Primary current: 2200 A

Required Area: 625 mm^2

Allowed Thickness: 6.6 mm

Lets use 5 times 25x5 mm copper stripes with 0,2 mm insulation in between and cover the whole with 0.5 mm paper.

Our total dimensions will be around **27x27 .**

*Secondary*

Current density of Secondary: 3,5 A/mm^2

Secondary current: 22 A

Required Area : 6,25 mm^2

Allowed Thickness : 6.6 mm

In Between insulation

Let’s use 2,5x2,5 mm copper stripe

Our total dimensions will be around **2,9x2,9 .**

**Selecting Number of Turns, Core dimensions, Winding dimensions**

Turns are selected in excel by optimizing the losses (the point is selected approximately by taking the copper loss a bit higher than the core loss)

Primary turns: 20

Secondary turns: 2000

Required core area: =V/(4,44\*f\*B\*N) =3000/(4,44\*500\*1\*20)= 0,0675676 m^2

Real Core area= stacking factor\*core area =0,9\*0,0675676=0,075 m^2

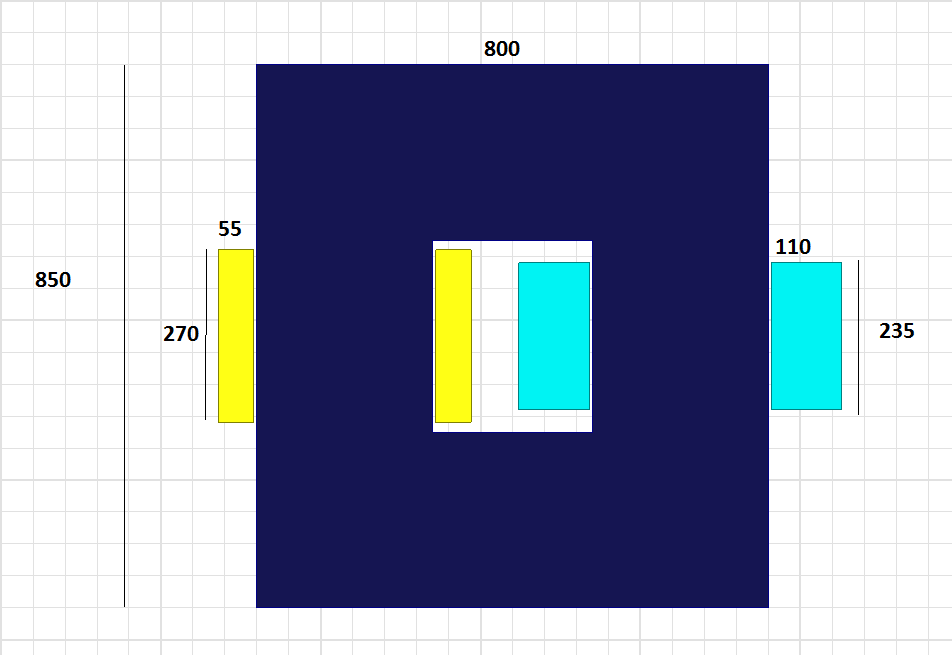
\*Core is assumed square, depth of the core = 0,2739983m

**Winding Dimensions**

Windings are assumed to be square, length of the wires is found by multiplying the number of turns with the avg winding length. Calculations are given in excel. A 2 meters of safety length is added for both primary and secondary winding.

\*A 80 mm oil gap is put between the primary and the secondary winding.

Winding and core dimensions 2D visiual:



Dimensions are in millimeters.

**Loss Calculations**

Core loss = total weight\*W/kg\*stacking factor

Copper loss = length\*resistivity at 110 C/ area

Calculations are a done in excel

Core loss= 8,35 kW

Copper loss= 8,87kW

Total loss = 17,22 kW

Efficiency= 6500/(6500+17,22) =0,997

**Excel Table**



**Equivalent Circuit Parameters**

Rprimary: 0,00091 ohm (from table)

Rsecondary: 9,204 ohm (from table)

Rcore : V^2/P =1078 ohm

Lmagnetazing = N^2/Reluctance (leakage is ignored since it will be small in compare)



L leakage:

Assume 4 pu leakage reactance:

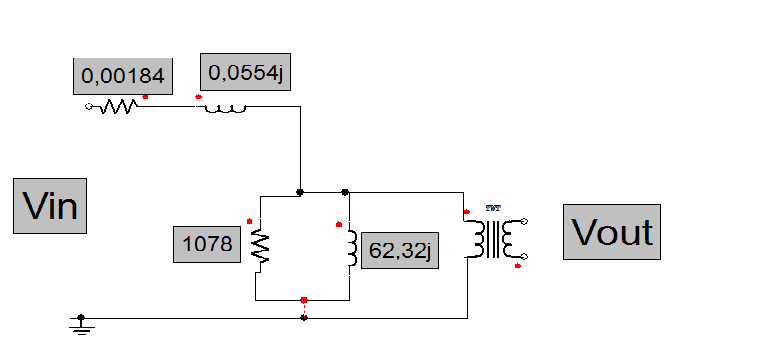
Primary referred reactance = 0.04\*V^2/S = 0,0554j

Lets assume reactances are shared as 65 percent secondary , 35 percent primary

Primary leakage inductance: 0,35\*0,0554/(2\*3,14\*500)=6,18 uH

Secondary leakage inductance: 10^4\*0,65\*0,0554/(2\*3,14\*500)=0,11 H

Primary referred circuit



Voltage Drop: Ignore the copper resistance since it is too small to compare,

2200\*0,0554 =121,88 volts

We can compensate this with adding one more layer ( 80 turns ) of secondary winding. ( design has enough space)

New turns ratio 20/2080

V-Vdrop=3000-121,88=2878

2878\*2080/20 =299,3 kV at full load

Voltage taps may be added for enhanced voltage control

New excel table according to 20/2080



**Appendix 1**

**Fem method for Inductance calculation**