Fundamentals of Power Electronics
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Lecture – 66
Inductor Design

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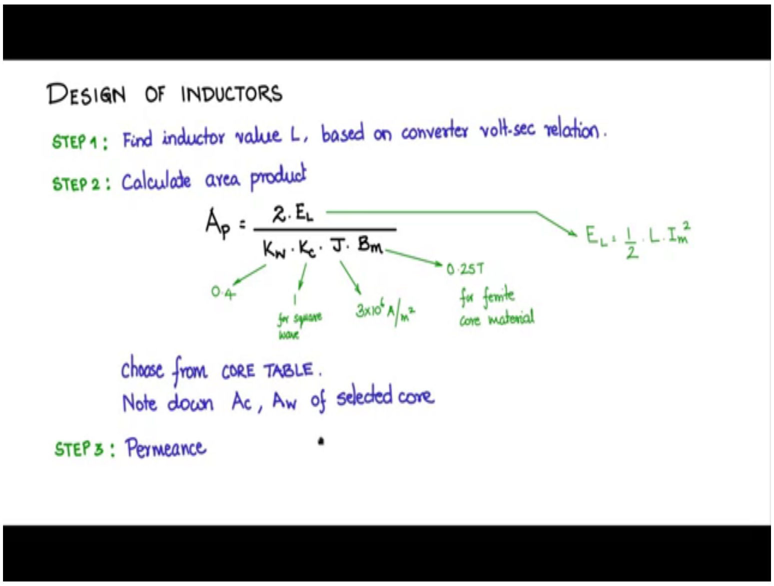

Let us down write down the steps for designing the inductor. Step 1. Step 1: Find the value of the inductor now this is something that we have done when we studied the various DC-DC converters based on the converters volt second balance relationship we were able to find the value of L. Step 2 onwards we proceed calculate the area product. So, area product A p is given by 2 E L for inductor 2 into energy max energy that the inductor can store K w, K c, J, B m.

The energy E L is given by half into L into I m square. So, you know what the current flowing through the inductor L values obtained from step 1, I m is known from the converter operation what is the maximum value of current you can calculate E L. K w as I said is an empirical value 0.4 (Refer Time: 01:42) wise K C is equal to 1 for square wave and for various other ways you can evaluate, J is 3 ampere mm square or 3 into 10 to the power of 6 amp per meter square B m is the flux density 0.25 Tesla for ferrite core materials. So, we can evaluate the value of A P.

After evaluating the value of the area product choose from the core table. So, you have to look into the datasheet of cores and go through the table of area products. I will show a typical example of the core table.

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Properties of Few Ferrite Cores

Cores without air gap	Mean length per turn (mm)	Mean magnetic length l_m (mm)	Core cross-section area A_c (mm^2)	Window area, A_w (mm^2)	Area product A_p (mm^4)
Pot Cores					
P18/11	35.6	26	43	27	1161
P26/16	52	37.5	94	53	4982
P30/19	60	45.2	136	75	10200
P36/22	73	53.2	201	101	20301
P42/29	86	68.6	264	181	47784
P66/56	130	123	715	518	370370
EE Cores					
E20/10/5	38	42.8	31	47.8	1481
E25/9/6	51.2	48.8	40	78	3120
E25/13/7	52	57.5	55	87	4785
E30/15/7	56	66.9	59.7	119	7104.3
E36/18/11	70.6	78	131	141	18471
E42/21/9	77.6	108.5	107	256	27392
E42/21/15	93	97.2	182	256	46592

Here is a typical core table I have taken it from the appendix of a book. So, you see cores without air gap, ok. These are high permeability cores and you need to introduce air gap if you want to use it for inductor purposes, for transformer purposes you can use it directly. So, there high permeability transformer cores, but you can use it for inductors too if you provide the proper air gap and reduce the permeability.

So, this is this column is the mean length per turn the mean magnetic path length l m that we have been using in various equations is this. See, there are various types of cores part cores this is the first the first top view rows of a pot cores the core cross section area you see this is the core cross section area the window area this these are numbers for the window areas where given an mm square and convert it to meters meter square.

The area product now this is what we need to be concerned about interested in after your calculated, you need to you need to go down this and then choose an appropriate area product.

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E25/9/6	51.2	48.8	40	78	3120
E25/13/7	52	57.5	55	87	4785
E30/15/7	56	66.9	59.7	119	7104.3
E36/18/11	70.6	78	131	141	18471
E42/21/9	77.6	108.5	107	256	27392
E42/21/15	93	97.2	182	256	46592
E42/21/20	99	98	235	256	60160
E65/32/13	150	146.3	266	537	142842
UU Cores					
UU 15	44	48	32	59	1888
UU 21	55	68	55	101	5555
UU 23	64	74	61	136	8296
UU 60	183	184	196	1165	228340
UU 100	29.3	308	645	2914	1879530
T 10	12.8	23.55	6.2	19.6	121.52
T 12	19.2	30.4	12	44.2	530.4
T 16	24.2	38.7	20	78.5	1570
T 20	25.2	47.3	22	95	2090
T 27	34.1	65.94	42	165.1	6934.2
T 32	39.6	73	61	165.1	10071.1
T 45	54.7	114.5	93	615.7	57260.1

You also have EE cores you can decide on the type on the shape of the core and then appropriately choose the core of a specific area product.

So, whatever you have calculated and let us say your calculated some 18000 you go down and choose a core which is greater than 18000 like that and once you have chosen that note down the A c cross section area, A w window area. So, like that there are few other cores you have the UU cores, you have the toroids. So, the data so, look at the datasheet to get a list of cores there are many many cores available and mainly look for the area product.

After you have chosen a particular core from the core table note down the cross section area ac and the window area aw of the selected core and subsequently after this step you will use this value of A c and A w for all other next calculations.

Step 3: permeance, let us find out the permeance for the core this is the next important step that you need to do.

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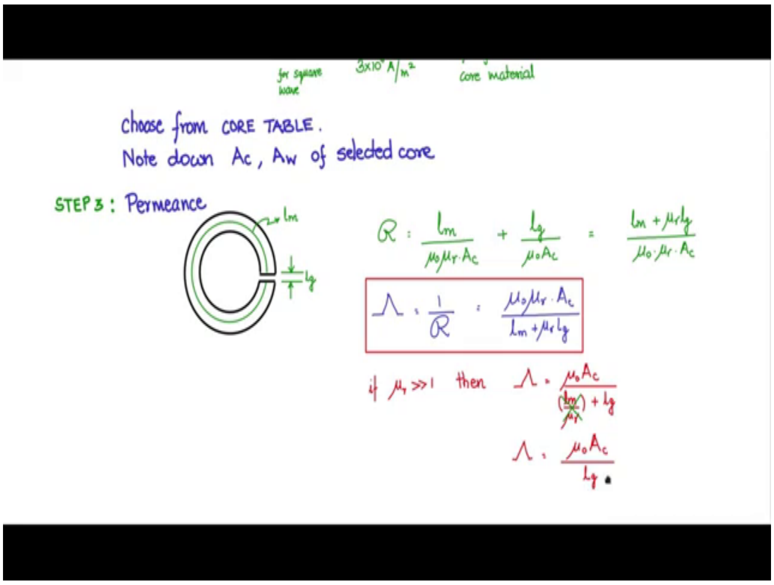

So, consider a core, like this. I have taken a circular core, toroidal core and then I have cut open like that I have introduce an air gap. Now, there is an air gap l g and the remaining is l m mean magnetic path length. What is the reluctance? Reluctance is having two parts, one is this part. So, I will take approximately lm divided by mu naught mu r A c core cross section area and reluctance of this part which is l g by mu naught A c and you can combine them you will get l m plus mu r l g by mu naught mu r A c.

What is permeance? 1 by reluctance which is mu naught mu r A c divided by l m plus mu r l g. So, this is the permeance of the core. Now, if mu r is much much greater than one like in ferrite 2000 to 2500 or even 3000, then you will see that permeance reduces further permeance is equal to mu naught A c I will divide by numerator and denominator by mu r l m by mu r plus l g; mu r being very large this term will vanish becomes insignificantly small and the permeance becomes mu naught A c by l g. So, in this high permeance cores when you want to introduce l g that is the air gap you could use this equation to quickly get the value of the permeance.

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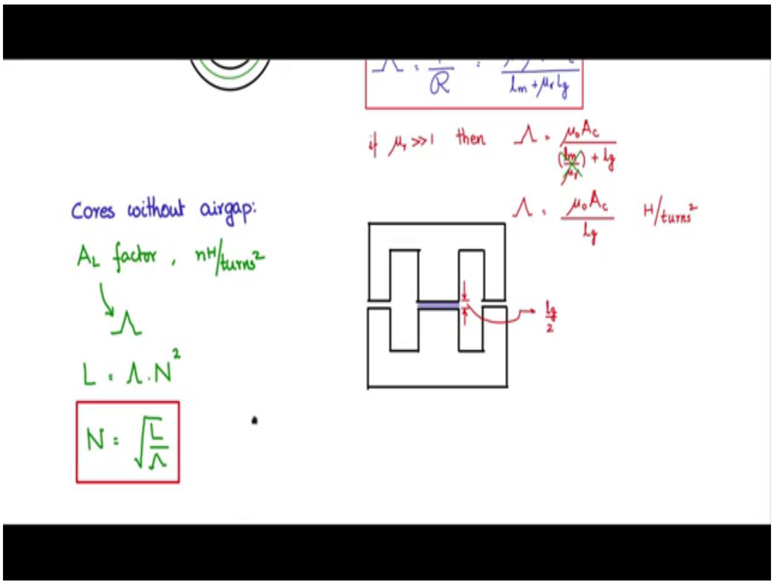

Now, take the example of the e core that we saw permeance is given Henry per turns square. So, if we take the EE core. So, let us say you want to introduce air gap. In the centre there you can cut a piece of paper or cut a piece of miller and then place it there on the central arm and then place the former and then on top you will place the other half of the core. So, this will be your air gap introduced core.

Now, the air gap here that you need to introduce should be half the l g that you would like to have finally, because there is half l g here if I introduce then if you go along the core the flux goes along the core there is an air gap which automates automatically comes in here air gap that automatically comes in air, but this is a thinner cross section ah. So, you will see that when you give l g by 2 here, then the overall l g throughout the core will land up as l g. So, give only l g by 2.

So, if you have calculated let us say you want a particular permeance and you have calculated that knowing A c mu naught and let us say for a given permeance you want this particular l g or for a given l g this is the permeance, then you introduce l g by 2 here than use for permeance calculation l g.

In the case of high permeability transformer cores you will introduce l g , but sometimes in the market cores are available specifically for inductors without the air gap, but with lower permeability. So, they have they have been categorised with the factor call the A L factor and A L factors are units of nano Henry per turns square. In fact, A L factor is nothing, but permeance.

We know the inductor value L is equal to permeance into n square. So, from this relationship the number of turns is equal to L by permeance L by permeance square root. So, using this relationship you can find out the number of turns that are required for the inductor for that particular selected core.

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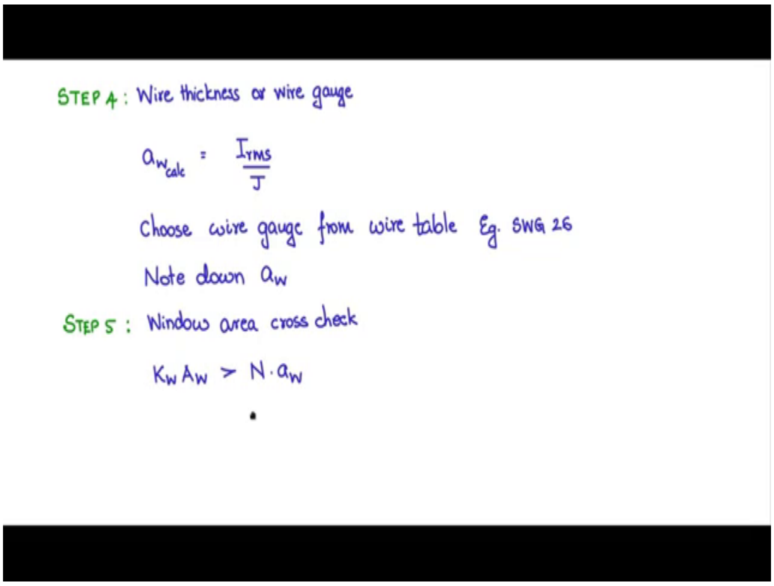

Next, step 4: we have to find out the wire thickness or the wire gauge. So, let us calculate the cross section area of the wire a w calculated which is I rms the rms value of the current flowing through the inductor wires divided by J the current density it is 3 amp per m m square. Then after having calculated go to the wire table and from the wire table list choose a wire gauge from the wire table which is having a w greater than a w calculated and then choose the wire gauge which is normally given in terms of standard wire gauges, SWG – standard wire gauges. For example, SWG 26.

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Wire Size Table

SWG	Diameter with enamel (mm)	Area of bare conductor (mm²)	R/km @20°C Ω	Weight (kg/km)
45	0.086	0.003973	4,340	0.0369
44	0.097	0.005189	3,323	0.0481
43	0.109	0.006567	2,626	0.061
42	0.119	0.008107	2,127	0.075
41	0.132	0.009810	1,758	0.0908
40	0.142	0.011675	1,477	0.1079
39	0.152	0.013700	1,258	0.1262
38	0.175	0.018240	945.2	0.1679
37	0.198	0.023430	735.9	0.2202
36	0.218	0.029270	589.1	0.2686
35	0.241	0.035750	482.2	0.3281
34	0.264	0.042890	402	0.3932
33	0.287	0.050670	340.3	0.465
32	0.307	0.059100	291.7	0.5408

Let me show you a typical wire table. This is a typical wire table wire size table. You see the first column SWG standard wire gauges given in terms of these numbers the higher the value of this SWG number thinner the wire.

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32	0.307	0.059100	291.7	0.5408
31	0.33	0.06818	252.9	0.6245
30	0.351	0.07791	221.3	0.7121
29	0.384	0.09372	184	0.8559
28	0.417	0.11100	155.3	1.014
27	0.462	0.13630	126.5	1.245
26	0.505	0.16420	105	1.499
25	0.561	0.20270	85.1	1.851
24	0.612	0.24520	70.3	2.233
23	0.665	0.29190	59.1	2.655
22	0.77	0.39730	43.4	3.607
21	0.874	0.51890	33.2	4.702
20	0.978	0.65670	26.3	5.939
19	1.082	0.81070	21.3	7.324

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SWG	Diameter with enamel (mm)	Area of bare conductor (mm^2)	R/km @20°C Ω	Weight (kg/km)
18	1.293	1.16700	14.8	10.537
17	1.501	1.589	10.8	14.313
16	1.709	2.075	8.3	18.678
15	1.92	2.627	6.6	23.64
14	2.129	3.243	5.3	29.15
13	2.441	4.289	4	38.56
12	2.756	5.48	3.1	49.22
11	3.068	6.818	2.5	61
10	3.383	8.302	2.1	74
9	3.8	10.51	1.6	94
8	4.219	12.97	1.3	116

So, if you go down you will see that SWG 19 or SWG 8 will be a very very thick copper wire SWG 45 will be a airline thin wire. So, you have various informations about the wire the diameter with enamel area of the bare conductor this is the area of the bare conductor is aw that we have been using in the equations and the weight so on so forth.

So, go down the wire table look at this particular column area of the wire cross section of the bare conductor without the enamel. So, go and pick that particular row which is having A w greater than the one calculated and choose that particular wire gauge standard wire gauge. For example, if it is coming greater than this value you can say SWG 40 or SWG 39. So, in this way you will pick the standard wire gauges from the wire gauge table so that you can buy it from the market.

So, after you choose you note down the value of A w of the selected wire gauge and use that to do a window area cross check what it means is that, you have to ensure that this inequality K w A w is greater than N a w means that the window area is available window area is able to accommodate all the turns having this wire cross section then your design is complete for the inductor.