UNIT -1

DESIGN OF FIELD SYSTEM AND ARMATURE

PART-A

1. Define specific electric loading [NOV/DEC2016,NOV/DEC2017,NOV/DEC2019]

It is defined as the ratio of total number of ampere conductors and the armature periphery at the air gap.

$ac = \frac{I_z{}^{z}}{\lambda D}$ 2. What are the factors that affect the size of rotating machine?[Nov/Dec 2016]

Speed, output, coefficient, specific electric loading, specific magnetic loading.

3. Write down the classification of magnetic materials [MAY/JUNE 2015]

(i) Soft magnetic materials

(ii) Hard magnetic materials

(or)

(i)Ferro magnetic materials

(ii)Paramagnetic materials

(iii)Diamagnetic materials

4. What are the major considerations in electrical machine design [MAY/JUNE 2013]

The major considerations to achieve a good electrical machine are specific electric loading, specific magnetic loading, temperature rise, efficiency, length of wire gap and power factor.

5. Define gap contraction factor for slots[NOV/DEC 2014]

It is defined as the ration of reluctance of air gap of slotted armature to reluctance of air gap of smooth armature.

6. What is peripheral speed? Write the expression for peripheral speed of rotating machine [NOV/DEC 2013]

The peripheral speed is a translational speed that may exist at the surface of the factor, while it is rotating.

(Translational speed equivalent to the angular speed at the surface of the ratio)

$V_a = \lambda Dn$ m/sec

D = diameter of rotar in m

N = speed of rotar in rps.

7. List the Indian Standard Specifications for a transformer [NOV/DEC2017]

- ❖ IS 2026-1972: Specifications of power transformer.

8. List the Indian Standard Specifications for induction motor.

- ❖ IS 325 – 1966
- ❖ IS 1231 – 1974
- ❖ IS 4029 – 1967
- ❖ IS 996 – 1979

9. Give the expression for total Electric loading and total magnetic loading.

Total magnetic loading = $P\phi$

Total Electric loading = $I_z z$

10. What is super conductivity? List few of the materials and compounds that exhibits the property of super conductivity.

The state of material in which it has zero resistivity is called super conductivity. The super conductivity is obtained when temperature is brought down below the transition temperature. The super conductivity materials are mercury, metals and alloys.

11. Define heating time constant.

The heating time constant of a machine is the index of time taken by the machine to attain its final steady temperature rise.

$t_n = \frac{Gh}{S\lambda}$ secs

12. Define cooling time constant.

The cooling time constant is defined as the time taken by the machine for its temperature rise fall to 0.368 of its initial value.

$t_c = \frac{Gh}{S\lambda}$

13. Distinguish between continuous rating and short time rating of an electrical machine.

Continuous rating :- The output of machine is obtained continuously without exceeding the permissible temperature rise. The machines are permitted to overload upto 20% more than the specified rating.

Short time rating :- It is the output which a machine can deliver for a specified period and remaining duration in off position for a long to reach its cold conditions.

14. What are the major considerations to evolve a good design of electrical machine. [NOV/DEC2011]

(i) Cost

(ii) Durability

(iii) Small size and less weight

(iv) Wider temperature operating limits

15. Define space factor

It is defined as the ratio copper (or) conductor area to the total winding

$S_f = \frac{copper(or)conductorarea}{totalwindingarea}$

16. Define Short time rating.[NOV/DEC2017]

It is the output which a machine can deliver for a specified period and remaining duration in off position for a long to reach its cold conditions.

17. What are the different conducting materials used in rotating machines?[NOV/DEC2018]

Copper, Aluminium,Iron and Steel, Alloys of copper.

18. Mention the various duty cycles of motor.[NOV/DEC2018]

(i) Continuous duty.

(ii) Short time duty.

(iii) Intermittent periodic duty.

(iv) Intermittent periodic duty with starting.

(v) Intermittent periodic duty with starting and braking.

(vi) Continuous duty with periodic duty.

(vii) Continuous duty with starting and braking.

(viii) Continuous duty with speed changes.

19. Define specific and magnetic loading.[NOV/DEC2017]

Specific electric loading:

It is defined as the ratio of total number of ampere conductors and the armature periphery at the air gap.

$$ac = \frac{I_z^{\,z}}{\lambda D}$$

Specific magnetic loading:

The average flux density over the air gap of a machine is known as specific magnetic loading.

$$B_{av} = \frac{\text{Total flux around the air gap}}{\text{Area of flux path of the air gap}}$$

20. What are the causes of failure of insulation?[NOV/DEC2019]

The losses produced in the machine are converted in to heat energy, as a result of which various parts of the machine are heated .i.e. losses are produced mainly in iron parts of the machine which carry flux and conductor which carry current resulting in increase in temperature of iron and copper leads to insulation failure.

21. What are the factors that decide the choice of specific magnetic loading?[NOV/DEC2019]

(i) Maximum flux density in the iron parts.

(ii) Magnetizing current.

(iii) Core losses or iron losses.

PART – B

1. Calculate the apparent flux density at a particular section of tooth from the data: Tooth width = 12mm, slot width = 10mm, gross core length = 0.32m, No. of ventilating ducts = 4 with each 10mm wide, real flux density = 2.2 wh/ m^2 . Permeability of teeth corresponding to real flux density = 3.14* 10^{-6} H/m. stacking factor = 0.9 [NOV/DEC 2016]

Solution:-

Magnetizing force

(or)

mmf per metre} H = $\frac{B}{\mu}$

Bread = 2.2 wb/ m^2

Permeability = μ = 3.14 λ 10^{-6}

'at' = $\frac{22}{3.14\lambda10^{-6}}$ = 70,063 A/m

Net iron length L_i = 0.9 (0.32 -4 λ 10^{-3})

= 0.252m

L_i = K_i (L- $n_d w_d$)

Ki = stacking factor, nd=no of ventilating ducts

Wd = width of each duct

Slot pitch y_s = $w_t + w_l$ = 12+10 = 22m

$$K_s = \frac{Ly_s}{L_iW_t} = \frac{0.32*22*10^{-6}}{0.252*12*10^{-3}}$$

Apparent flux density

Bap = Breal + 4 $\lambda *10^{-7}$ at (k_s^{-1})

= 2.2+ 4 $\lambda *10^{-7}$ * 70,068 (2.328)

=2.317 wb/ m^2 .

2. Calculate the mmf required for the airgap of a machine having core length 0.32m including 4ducts of 10mm each. Pole arc = 0.19m, slot pitch = 65.4m, slot opening = 5mm, airgap length = 5mm, flux per pole = 52mwh. Given carter's coefficient is 0.18 for opening 1gap = 1 and is 0.28 opening per gap = 2.[Nov/Dec 2016]

Solution:-

Ratio $= \frac{slotopening}{gaplength} = \frac{5}{5} = 1$

Carter's coefficient for slots 0.18. This is a salient pole machine with semi-closed slots gap contraction factor for slots $K_{gs} = y_s = \frac{y_s}{K_c W_o}$

$\frac{65.4}{65.4 - 0.18*5}$ =1.014

Ratio= $\frac{ductlength}{gaplength} = \frac{10}{5} = 2$

Carter's coefficient for ducts K_{cd} =0.28 gap contraction fctor for ducts

$$K_{gd} = \frac{L}{L - k_{cd} n_d W_d}$$

$$\frac{0.32}{0.32 - 0.28*4*1*10^{-3}}$$

=1.036

Total gap construction factor = K_g = 1.014*1.036

= 1.05

Flux density at the centre of pole $B_g = \frac{flux / pole}{polearc * corelength}$

$$\frac{52*10^{-3}}{0.19*0.32} = 0.854 wh/m^2$$

mmf required for air gap AT_g = 800000 kg lg lg

$=800000*1.05*0.854*5*10^{-3}$

=3587A

3. State and explain the of hydrogen cooling as applied to turbo alternator [NOV/DEC2016]

- ❖ Hydrogen when mixed with air forms an explosive mixture over a very wide range(4y to 767) of hydrogen in air.
- ❖ Therefore the frame of hydrogen cooled machine has to be made strong enough to withstand possible internal explosions without suffering serious damage.
- ❖ All joist in cooling circuits are made gas tight oil film shaft seals are used to prevent leakage of hydrogen
- ❖ The risk of explosion in the machine casing are reduced by maintaining the hydrogen above atmospheric pressure so that any leakage is from machine to atmosphere where the hydrogen can be quickly dissipated [105KN/ m^2 Pressure is wpt]
- ❖ Fans maintained on the rotar circulate hydrogen through the violating ducts and internally arranged gas coolers
- ❖ The gas pressure is maintained by an automatic regulating and reducing valve controlling the supply from gas cylinders.
- ❖ When filling and emptying the casing of machine, an explosive hydrogen air mixture must be avoided, so that air is first displaced by carbon dioxide gas before hydrogen gas is admitted. The process is reversed when emptying the machine
- ❖ The purity of hydrogen is checked by measuring its thermal conductivity.

4. The temperature rise of a transformer is $25^{*}C$ after one hour and $37.5^{*}C$ after two hours of starting from cold conditions. Calculate its final steady temperature vise and the heating time constant, it its temperature falls from the final steady value to $40^{*}C$ in 1.5 hour when disconnected. Calculate its cooling time constant. The ambient temperature is $30^{*}C$ [MAY/JUNE2016]

SOLUTION:-

$\theta_1 = 25^{*}C,$ t = 1hr

$\theta_2 = 37.5^{*}C,$ t = 2hr

$\theta_a = 30^* C$

$$\theta_1 = \theta_m (1 - e^{\frac{t}{T_n}})$$

$$\theta_2 = \theta_m (1 - e^{\frac{-t}{T_n}})$$

$$25 = \theta_m (1 - e^{\frac{-t}{T_n}})$$

$$37.5 = \theta_m (1 - e^{\frac{-t}{T_n}})$$

$$\frac{37.5}{25} = \frac{1 - e^{\frac{-t}{T_n}}}{1 - e^{\frac{-t}{T_n}}} = \frac{(1 + e^{\frac{-1}{T_n}})(1 - e^{\frac{-1}{T_n}})}{(1 - e^{\frac{-1}{T_n}})}$$

$$\frac{37.5}{25} = \frac{(1 + e^{\frac{-1}{T_n}})}{1}$$

$$1 + e^{\frac{-1}{T_n}} = \frac{25}{37.5}$$

$$e - ^{\frac{-1}{T_n}} = \frac{25}{37.5} - 1$$

$$\theta_m = \frac{25}{e - ^{\frac{-1}{T_n}}}$$

5. Describe the classification of insulating materials used to electrical materials [May/June216/

OR

What are the electrical properties of insulating materials? Classify the insulating materials based on thermal considerations.[NOV/DEC2018]

Insulating materials.

To avoid any electrical activity between parts at different potentials, insulation is used. An ideal insulating material should possess the following properties.

1) Should have high dielectric strength.
2) Should with stand high temperature.
3) Should have good thermal conductivity
4) Should not undergo thermal oxidation
5) Should not deteriorate due to higher temperature and repeated heat cycle
6) Should have high value of resistivity (like 1018 Ωcm)
7) Should not consume any power or should have a low dielectric loss angle δ
8) Should withstand stresses due to centrifugal forces (as in rotating machines), electro dynamic or mechanical forces (as in transformers)
9) Should withstand vibration, abrasion, bending
10) Should not absorb moisture
11) Should be flexible and cheap
12) Liquid insulators should not evaporate or volatilize

Thermal considerations

Classification of insulating materials based on thermal consideration

Insulation class		Maximum operating temperature in ℃	Typical materials
Previous	Present		
Y		90	Cotton, silk, paper, wood, cellulose, fiber etc., without impregnation or oil immersed
A	A	105	The material of class Y impregnated with natural resins, cellulose esters, insulating oils etc., and also laminated wood, varnished paper etc.
E	E	120	Synthetic resin enamels of vinyl acetate or nylon tapes, cotton and paper laminates with formaldehyde bonding etc.,
B	B	130	Mica, glass fiber, asbestos etc., with suitable bonding substances, built up mica, glass fiber and asbestos laminates.
F	F	155	The materials of Class B with more thermal resistance bonding materials
H	H	180	Glass fiber and asbestos materials and built up mica with appropriate silicone resins
C	C	>180	Mica, ceramics, glass, quartz and asbestos with binders or resins of super thermal stability.

- The insulation system (also called insulation class) for wires used in generators, motors transformers and other wire-wound electrical components is divided into different classes according the temperature that they can safely withstand.
- As per Indian Standard (Thermal evaluation and classification of Electrical Insulation,IS.No.1271,1985,first revision) and other international standard insulation is classified by letter grades A,E,B,F,H (previous Y,A,E,B,F,H,C).
- The maximum operating temperature is the temperature the insulation can reach during operation and is the sum of standardized ambient temperature i.e. 40 degree centigrade, permissible temperature rise and allowance tolerance for hot spot in winding. For example, the maximum temperature of class B insulation is (ambient temperature 40 + allowable temperature rise 80 + hot spot tolerance 10) = 130ºC.
- Insulation is the weakest element against heat and is a critical factor in deciding the life of electrical equipment. The maximum operating temperatures prescribed for different class of insulation are for a healthy lifetime of 20,000 hours. The height temperature permitted for the machine parts is usually about 2000C at the maximum. Exceeding the maximum operating temperature will affect the life of the insulation. As a rule of thumb, the lifetime of the winding insulation will be reduced by half for every 10 ºC rise in

temperature. The present day trend is to design the machine using class F insulation for class B temperature rise.

6. Discuss in detail the factors affecting the choice of specific electric and magnetic loading in rotating machines.[NOV/DEC2017,NOV/DEC2018]

Specific magnetic loading (B_{av})

The specific magnetic loading is defined as the average flux density over the air-gap of a mixture

$$Bav = \frac{totalfluxaroundtheair-gap}{areaoffluxpathattheair-gap} = \frac{p\theta}{\lambda DL}$$

Factors that affect the choice of specific magnetic loading

(i) Maximum flux density in iron

Maximum flux density will occur in teeth (particular narrow end of the teeth)

ie Bt is not to exceed maximum specified limit 2 to.2 wh/m^2

small machine (which have very narrow teeth width) will have lower specific magnetic loading.

(ii) Magnetising current

Increase in specific magnetic loading will have result in increased magnetising current. The value of magnetising current is not a serious consideration in d.c machine, But an increased value of magnetising current in induction result into low power factor

(iii) Core loss

Increase in specific magnetic loading will also increase the core loss and consequently decreased efficiently and an increased temperature rise.

(iv) Frequently of operation of armature

High speed d.c machine (or) high frequently are machine, specific magnetic loading must be reduced in order to get lower iron loss so that resonable efficiency is maintained

(v) Size of machine

At a given specific electric loading, if lineal dimension is increased by x times, then core loss will increase by x^3 times & output will increase by x^4 times.

Then for the same percentage of core loss in two machines, specific magnetic loading may be increased slightly for the larger machine

Typical value of bow (wh/m^2)

0.4 to 0.8 – D.C Machine

0.3 to 0.6 – Induction motor

0.52 to 0.65 – synchronous machine

Specific Electric Loading (ac)

The specific electric loading is defined as the number of armature (or stator) ampere conductors per metre of armatue (or stator) pheriphery at the air-gap

$$ac = \frac{totalarmatureampereconductors}{armaturepheripheryatair-gap} = \frac{I_2 Z}{\lambda D}$$

Choice of specific Electric loading

(i) Permissible temperature rise

(ii) Voltage

(iii) Size of machine

Permissible temperature rise

Heat dissipated per unit area of armature surface is proportional to specific electric loading, ie limiting value of specific electric loading is decided by maximum allowable temperature rise and cooling coefficient

When better quality insulating materials, which can, high temperature rise, are used, then increased values of specific electric loading can be used

When better ventilation provided, then cooling coefficient value will be increased then increased values of specific electric loading can be used.

(i) Voltage

In high voltage machines greater insulation thickness is required, hence it is necessary reduce specific electric loading limit for high voltage machines.

(ii) Size of machine

The larger the machine the greater the slot depth and greater the specific electric loading

Typical values of ac in amp cord/metre

15000 to 50000 -> D.C machine

5000 to 45000 -> Induction motor

20000 to 40000 -> syn motor

5000 to 75000 -> turbo alternator

Types of duties and ratings

S1 – Continuous duty

S2 – Short time duty

S3 – Intermittent periodic duty

S4 – Intermittent periodic duty with starting

S5 - Intermittent periodic duty with starting & braking

S6 – Continues duty with intermittent periodic loading

S7 - Continues duty with intermittent periodic loading & Braking

S8 - Continues duty with intermittent periodic speed charges

Limitations in design

1. Saturation
2. Temperature rise
3. Insulation
4. Efficiency
5. Mechanical parts
6. Communication
7. Power factor
8. Consumers specifications
9. Standard specifications

Standard specification

The specifications are guidelines for the manufactures to produce economic products without compromising quality. The manufacture who are compiling with the standards will be issued a certification for their products

1. Standard rating of machines
2. Types of enclosure
3. Standard dimensions of conductors to be used.
4. Method of making rating & name plate details
5. Performance specification to be met
6. Types of insulation and permissible temperature rise
7. Permissible loss and range of efficiency
8. Procedure for testing of machine parts & machine
9. Auxiliary equipments to be provided
10. Cooling methods to be adopted

7. Derive an expression for the heating and cooling curve in electrical machines.

[NOV/DEC2017 /NOV/DEC2019]

Let $Q \rightarrow$ Power loss or heat developed, W

$G \rightarrow$ Weight of active parts in m/c, kg

$h \rightarrow$ Specific heat, J/kg – ^{o}C

$S \rightarrow$ cooling surface, m^2

$\lambda \rightarrow$ Specific heat dissipation , W/m^2 – ^{o}C,

$C = 1/\lambda$ = cooling co – efficient ^{o}C – m^2/w, $\theta \rightarrow$ temperature rise at anytime t, ^{0}C

$\theta_m \rightarrow$ final steady state temperature rise ^{o}C, $\theta_n \rightarrow$ final steady state temperature rise while cooling, ^{0}C

$\theta_i \rightarrow$ Initial temperature rise, ^{o}C $t_h \rightarrow$ heating time constant, s

$t_c \rightarrow$ cooling time constant, s

HEATING:

During 'dt' let temperature rise be dQ

Total heat generated = Q dt

Heat energy stored or absorbed by a body = Weight of in body X specific heat X difference in temp.

$$= G\ h\ d\theta$$

The heat energy dissipated by the body into the ambient medium due to radiation, conduction and convection = Specific heat dissipation X cooling surface X temperature

$$= S\ \lambda\ \theta\ dt$$

As heat developed in the machine (body) is equal to heat stored in the parts plus the heat dissipated

$$Q\ dt = S\ \lambda\ d\theta + G\ h\ d\theta.$$

There is no further temperature rise where machine a final steady state temperature rise Q_m at t = λ . under this condition the rates of heat production and dissipation are equal (i.e.) dQ = 0, Q = Q_m

$$\therefore Q\,dt = S\lambda\,\theta_m\,dt \Rightarrow Q = S\lambda\,\theta_m \Rightarrow \boxed{Q_m = \frac{Q}{S\lambda}}$$

Also G h dθ = Q dt – S λ θ dt

$$= (Q - S\ \lambda\ \theta)\ dt \qquad \Rightarrow \frac{d\theta}{dt} = \frac{Q - S\lambda\theta}{Gh} = \frac{Q}{Gh} - \frac{S\lambda\theta}{Gh}$$

If the cooling medium is not present then S = 0

$$\therefore Q\,t_h = Gh\frac{Q}{S\lambda} \Rightarrow Q\,dt \Rightarrow G\,h\,dQ \Rightarrow Qt = G\,hQ$$

At t = t_h → time taken reach Q_m, Qt_h = G h Q_m

$$\therefore Q\,t_h = G\,h\frac{Q}{s\lambda} \Rightarrow \boxed{t_h = \frac{Gh}{S\lambda}} \rightarrow$$ heading time constant

$$dt = \frac{d\theta}{\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta}$$ Upon solving $$t = \frac{Gh}{S\lambda}\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}Q\right) + k$$

Where k → integration constant and it can be obtained by applying boundary conditions when t = 0, Q = Q_j (temperature rise over the ambient)

$$0 = \frac{Gh}{S\lambda}\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}Q_i\right) + k$$

$$\therefore k = \frac{Gh}{S\lambda}\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta_i\right) \Rightarrow k = t_n \log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta_i\right) \because t_n = \frac{Gh}{S\lambda}$$

$$\therefore t = -t_h \log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta\right) + t_n \log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta_i\right)$$

$$\therefore t = -t_h\left[\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta\right) - t_n \log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta_i\right)\right]$$

$$t = -t_h \log_e\left[\frac{\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta}{\frac{G}{Gh} - \frac{S\lambda}{Gh}\theta_i}\right] \Rightarrow t = -t_h \log_e\left(\frac{Q - S\lambda\theta_e}{Q - S\lambda\theta_i}\right)$$

$$\frac{-t}{t_h} = \log_e\left(\frac{Q_m - \theta}{Q_m - \theta_i}\right), \text{upon solving } \theta = \theta_m\left(1 - e^{-t/th}\right) + \theta_i e^{-t/th}$$

Equation of temperature rise with time is $\theta = \theta_m (1- e^{-t/th})$ The heating curve of the machine is obtained by replacing t by t_h

$$\therefore \theta = \theta_m\left(1 - e^{-th/th}\right) \Rightarrow \theta = \theta_m\left(1 - e^{-1}\right)$$

COOLING:

W. K. T Q dt = G hdθ + S λ θ dt

The solution of above equation $$t = \frac{Gh}{S\lambda}\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta\right) + k$$ The values of k is obtained using t = 0, $\theta = \theta_i$

$$\therefore o = \frac{-Gh}{S\lambda}\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta_i\right) + k$$

$$\therefore k = \frac{Gh}{S\lambda}\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta_i\right)$$

$$\therefore t = -\frac{Gh}{S\lambda}\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta\right) + \frac{Gh}{S\lambda}\log_e\left(\frac{Q}{Gh} - \frac{S\lambda}{Gh}\theta_i\right)$$

$$\text{If } t_c = \frac{Gh}{S\lambda}, \text{then } t = -t_c\left[\log_e\left(\frac{\frac{Q}{Gh}-\frac{S\lambda}{Gh}\theta}{\frac{Q}{Gh}-\frac{S\lambda}{Gh}-\theta_i}\right)-\log_e\left(\frac{Q}{Gh}-\frac{S\lambda}{Gh}\theta_i\right)\right]$$

$t_c \rightarrow$ cooling time constant

$$\therefore t = t_c\left[\log_e\left(\frac{\frac{Q}{Gh}-\frac{S\lambda}{Gh}\theta}{\frac{Q}{Gh}-\frac{S\lambda}{Gh}-\theta_i}\right)\right]$$

Now $\theta_n = \frac{\theta}{S\lambda}$ final steady temperature while cooling and solving

$$\theta = \theta_n\left(1-e^{-t/te}\right)+\theta_i e^{-t/te}, \text{when } \theta_n = 0, \text{then } \theta = \theta_i\, e^{-t/te} \text{At } t = t_e\ \theta = \theta_i e^{-1}$$

$$\Rightarrow \boxed{\theta = 0.368\theta_i}$$

8. Write short notes on standard specifications. List the parameters involved in marking the standard specifications.[NOV/DEC2018]

The standard specifications are the specifications issued by the standard organization of a country. The standard specifications serve as guideline for the manufacturers to produce quality products at economical prices.

Standardisation and standard specification play an important role in the choice design, manufacture and operation of any apparatus.

✓ To the user, standardisation means interchangeability of equipment and spares.

✓ To designer, it means rigidity.

The standard specifications issued for electrical machines,

(*i*) Standard ratings of machines.

(*ii*) Types of enclosure.

(*iii*) Standard dimensions of conductors to be used.

(*iv*) Method of marking ratings and name plate details.

(*v*) Performance specifications to be met.

(*vi*) Types of insulation and permissible temperature rise.

(*vii*) Permissible loss and range of efficiency.

(*viii*) Procedure for testing of machine parts and machines.

(*ix*) Auxillary equipments to be provided.

(*x*) Cocling methods to be adopted.

The name plate of a rotating machine shall be marked with appropriate items in the following list

1. Type of machine
2. Class of rating
3. Rated output
4. Rated voltage and current
5. Speed of machine
6. Class of insulation
7. Number and data of specification
8. Cooling methods
9. Manufacturer's name
10. Manufacturer's serial number or identification mark

Indian standards-these are issued by Indian Standards Institution

IS 325 – 1966	:	Specifications for 3ϕ induction motor
IS 1271 – 1958	:	Specifications for classification of insulating materials
IS 1231 – 1974	:	Specifications of dimensions in 3ϕ foot mounded induction motors
IS 4029 – 1967	:	Guide for testing 3ϕ induction motor
IS 1885 – 1973	;	Electro-technical vocabulary – transformer
IS 996 – 1979	:	Specifications of 1ϕ ac and universal motor
IS 2026 – 1962	:	Power transformer
IS 9499 – 1980	:	Conventions concerning electric and magnetic circuits
IS 1180 – 1972	:	3ϕ distribution transformer and outdoor type
IS 3639 – 1966	:	Fittings and accessories for power transformers
IS 7538 – 1996	:	Specifications for 3ϕ induction motor for centrifugal pumps
IS 4691 – 1968	:	Perfection of enclosures in rotating machinery
IS 9320 – 1979	:	Guide for testing dc machines
IS 5422 – 1969	:	Turbine type generators
IS 4800 – 1968	:	Specification for enamelled round wire

IS 12615 – 1986	:	Specifications for energy efficient induction motor
IS 7132 – 1973	:	Guide for testing synchronous machine
IS 8789 – 1996	:	Values of performance characteristics for 3ϕ induction motors
IS 1897 – 1962	:	Standard dimensions of bare copper strip
IS 13956 – 1994	:	Testing transformer

IEC standards – These are issued by International Electro-technical Commission

1. IEC 27 - 1971	:	Letter symbols to be used in electrical technology part-I general.
2. IEC 38 – 1975	:	IEC standard voltages
3. IEC 76 – 1976	:	Power transformers
4. IEC 50 – 1973	:	International electro technical vocabulary.

UNIT II

DESIGN OF TRANSFORMERS

PART A

1. What is window space factor (Nov /Dec 2016,Nov/Dec2019)

The Window space factor is defined as the ratio of copper area of window to total area of window.

2. How heat is dissipated in a transformer? [Nov / dec2016)

The heat dissipation in a transformer occurs by conduction, connection and radiation.

3. Distinguish between core type and shell type transformers (may / June 2016).

CORE TYPE	SHELL TYPE
1.Easy in design and construction	1.Comparatively complex
2.Has lap mechanical strength	2.Has high mechanical strength
3.Better heat dissipation from windings	3.Heat is not easily dissipated from windings since it is surrounded by core.

4. Why are the cores of large transformers built-up of circular section? (May/June2016)

*Circular cross section is preferred to obtain the optimum core within the circumscribing circle of core.

*To provide high tensile strength

*To keep the hot spot temperature within specified limits.

5. Why stepped core are generally used for transformer (May/ June 2015)

Or

What are the advantages of stepped core in transformers?[Nov/Dec2018]

When stepped cores are used the diameter of the circumscribing circle is minimum for a given area of the core, this helps in reducing the length of mean turn of the winding with consequence reduction in both cost of copper and copper loss.

6. Why circular coils are preferred in transformer (May / June 2015).

The excessive leakage fluxes produced during short circuit and over-load, develop sever mechanical stresses on the coils.

On circular coils these forces are radial and there is no tendency for the coil to change its shape. But on rectangular coils the forces are perpendicular to the conductors and ends to deform the coil in circular form.

7. Define the term voltage regulation. (May/June 2014)

It is defined as the ratio of difference between no-load voltage and full load voltage to no-load voltage.

8. Mention the various methods of cooling for larger power transformers.

*Oil natural air forced

- Oil natural water forced
- Oil forced air natural
- Oil forced air forced
- Oil forced water forced.

9. Classify the transformer according to cooling methods?

According to cooling methods the transformers can be classified as follows,

- ❖ Air Cooled transformer
- ❖ Oil cooled transformers
- ❖ Water cooled transformers

10. List the different types of windings used in core type transformers,

The different types of windings employed in core type transformer all.

- ❖ Cylinder winding
- ❖ Cross-over winding
- ❖ Helical winding
- ❖ Disc and cooking was disc winding,
- ❖ Double helical winding

- ❖ Aluminium foil winding
- ❖ Multi layer helical winding

11. What do you mean by stacking factor or Iron space factor?[Apr/May2011]

In transformers, the core is made of lamination and the laminations are insulated from each other by a thin coating of varnish. Hence when the laminations are stacked to form the core, the actual iron area will be less them the core area.

The ratio of iron area and total care area is called stacking factor.The value is usually 0.9

12. Define copper space factor.

The copper space factor is the ratio of conductor area and window area in case of transformers.

13. Write down the output equation of 1-phase and 3 phase transformers.

Single-Phase Transformer; $Q = 2.22 B_m f K_w A_w A_i \delta \times 10^{-3}$

Three Phase Transformer; $Q = 3.33 f B_m K_w A_w A_i \delta \times 10^{-3}$ kVA

14. What are the various types of transformers construction based,

- ❖ Care type x shell type
- ❖ Application based
- ❖ Distribution transformers
- ❖ Power transformers
- ❖ Special transformers
- ❖ Instruments transformers
- ❖ Electronics transformers

15. What are the factors to be considered for selecting the cooling method of transformers?

The choice of cooling method depends on kva rating of transformers, size, application and the site condition where and the site condition where it will be installed.

16. Classify the transformers according to cooling method?

According to cooling method the transformers can be classified as

- ❖ Air cooled transformers

- ❖ Oil cooled transformers
- ❖ Water cooled transformers

17. How to design the winding of a transformer?

The winding design consists of estimation of number of turns and area of cross section of winding conductions.

Usually the number of burns in low voltage winding is estimated by assuming ernf per turn and the turns of high voltage winding are estimated from the voltage ratio.

Number of turns in low voltage winding} equation

18. The voltage per turn of a 500kVA, 11kV/415V, Δ/Y three phase transformer is 8.7V. Calculate the number of turns per phase of LV and HV windings.[Apr/May 2005,Nov/Dec2019]

Solution:

Phase voltage of LV winding = $\frac{415}{\sqrt{3}} = 239.6v$ **(star connected)**

Phase voltage of HV winding = 11000V (delta connected)

Number of turns in LV windings = $\frac{\text{Phase voltage of LV winding}}{\text{Emf per turn}}$

$$= \frac{239.6}{8.7} = 27.54$$

= 28 turns

Number of turns in HV winding = No. of turns in LV winding X phase voltage ratio

$$28\,x\,\frac{11,000}{239.6} = 1285-5$$

= 1286 turns

19. What is tertiary winding?

Tertiary winding is also called as auxiliary winding it is provided for the following reasons. To supply small additional load at a different voltage

- To limit start circuit current.
- To indicate voltage in high voltage transformer

20. What are the advantage and disadvantage of stepped case?

Advantage

For the same area of cross – section the stepped cores will have lesser diameter of circumscribing circle than square mean turn of the winding with consequent reduction in caste of copper and copper loss.

Disadvantage

With large number of steps a large number of different sizes if laminations have to be used. This results in higher labour charges for shearing assembling different types of laminations.

21. How does a distribution transformer differ from a power transformer?[NOV/DEC2017]

Solution:

- Distribution transformer are used in distribution network where as power transformers are used in transmission networks
- Distribution transformer voltages are 11 KV, 6.6 KV, 3.3 KV, 440 V on the other hand power transformer voltage are 33 KV, 110 KV, 220 KV, 400 KV

Part B:

1. Derive the Output equation of Single phase transformer.

Output equation of single – phase transformer.

The induced emf in a transformer = E = 4.44fm T Volts

Emf per turn = E_t = E/T = $\frac{4.44 f \phi T}{T}$

$$\mathbf{E_t - = 4.44\, f \phi\, m}$$

Window Space factor = $\frac{\text{Conductor Area in window (AC)}}{\text{Total area of(AW) window}}$

$$\mathbf{AC = K_w}\, A_W$$

F = Current density = Same in both windings

$$S = \frac{I_P}{a_p} = \frac{I_S}{a_s}$$

$$a_p = \frac{I_P}{\delta} \;,\; d_s = \frac{I_S}{a_s}$$

If we neglect magnetizing mmf then primary Ampere turns = Secondary ampere turns

$$AT = Ip\,Tp = Is\,Ts$$

$$\text{Toatl copperArea in window} = \begin{pmatrix}\text{copper area of} \\ \text{Primary windings}\end{pmatrix} + \begin{pmatrix}\text{copper area of} \\ \text{Secondary windings}\end{pmatrix}$$

$$\text{Toatl copper Areain window} = \begin{pmatrix}\text{Number of primary} \\ \text{Turns}\end{pmatrix} + \begin{pmatrix}\text{Area of crosssection of} \\ \text{primary conductors}\end{pmatrix} + \begin{pmatrix}\text{Nubers of Secondary} \\ \text{burns}\end{pmatrix} x \begin{pmatrix}\text{area of cross section of} \\ \text{secondary conductor}\end{pmatrix}$$

$$= T_p a_p + T_s a_s$$

$$= T_p \text{ x } \frac{I_p}{\delta} + T_S \frac{I_S}{\delta}$$

$$= \frac{1}{\delta}\left(T_p\, I_p + T_s\, F_s\right)$$

$$= \frac{1}{\delta}\left[AT + AT\right]$$

$$AC\ \frac{2AT}{\delta}$$

$$AC = K_w\ A_w$$

$$K_w\ A_w\ \frac{2AT}{\delta}$$

$$AT = \frac{K_w\ A_w\,\delta}{2}$$

KVA Rating of single phase transformer is given by

$$KVA = Q = V_P I_P\ x10^{-3}$$

$$\underline{N}\ E_P\, I_P\ x10^{-3}$$

$$\therefore \underline{N}\ V_p$$

$$\frac{E_p}{T_p}\ TP\ x\ IP\ x\ 10^{-3}$$

$$= E_t\ AT\ x\ 10^{-3}$$

$$= 4.44\ f\ \phi m\ x\ \frac{1}{2}\ Kw\ Aw\ ^{\delta} x10^{-3}\ \phi m = BmAi$$

$$Q = 2.22\ f\ \phi m\ \ Kw\ Aw\ ^{\delta} x10^{-3}$$

$$Q = 2.22\ f\ BmAi\ AwKw^{f}\ x\ 10^{-3}$$

2. Derive the Output equation of three phase transformer.(Nov/Dec2018)

Output equation of three phase transformer the induced emf per phase E – 4.47f ϕm T

Emf per turn = E/T = 4.44 f ϕm T

$$K_w = \frac{A_C}{A_W}$$

$A_C = K_W \; A_W$

Note: one window is considered

Current density = $\delta = \frac{IP}{\delta P} = \frac{IS}{\delta}$

$$ap = I_P / \delta \;,\; as = \frac{I_s}{\delta}$$

On neglecting magnetising ampere turns

AT = ap Tp = a_s T_s

Total copper area in window = Ac = $2T_p \, a_p + 2 \, T_s \, a_s$

$$AC = 2Tp \, \frac{I_P}{\delta} + 2T_S \, \frac{I_S}{\delta}$$

$$= \frac{2}{8} \, (AT + AT)$$

$$A_C = \frac{4AT}{\delta}$$

A_C =Kw Aw

$$\frac{4AT}{\delta} = Kw \; Aw$$

$$AT = Kw \; Aw \, \delta \, x \, \frac{1}{4}$$

Q = 3Vp IP x 10^{-3} = 3 Ep Ip x 10^{-3} KA

$$= 3x \, \frac{Ep}{Tp} \; x \; Tp \; Ip \; x \; 10^{-3}$$

$$= 3x \; 1.1f\phi m \; x \; \frac{1}{4} \; x \; Kw \; Aw \, \delta$$

$$Q = 3.33f \; Bm \; AiAw \; Kwf \; X \; 10^{-3}$$

3. Calculate the core and window area required for a 1000KVA , 6600/400V, 50HZ , single phase core type transformer. Assume a maximum flux density of 1.25 wb/m^2 Voltage per turn = 30V. Window space facker = 0.32.

Given data

KVA = 1000, F = 50Hz Bm = 1.25 wn/m^2 Vp = 6600V, Vs = 400V , δ = 2.5 A / mm^2

Et = 30v , Kw = 0.32 1-phae case type.

Solution:

Emf per turn , Et -=- 4.44 $^{f\phi m}$ f

$$Qm = \frac{Et}{4.44f} = \frac{30}{4.44 \text{ x } 50} = 0.135 / wb$$

$$Bm = \frac{Qm}{Ai}$$

$$Ai = \frac{Qm}{Bm} \; \frac{0.1351}{1.25} = 0.108 \; m^2$$

$$= 0.108 \text{ x } 10^6 \; mm^2$$

Q = 2.22 f Bm Ai Kw Aw f x 10^{-3}

$$= \frac{1000}{2.22 \text{ x } 50 \text{ x } 1.25 \text{ x } 0.108 \text{ x } 0.32 \text{ x } 2.5 \text{ x } 10^6 \text{ x } 10^{-3}}$$

= 0.0834 m^2

= 0.834 x 10^6 mm^2

4. Determine the dimensions of care and window for a 5KVA, 50Hz, 1- phase core type transformer. A rectangular core is used with long side device as long as start 57 the window height is 3 times the width voltages per turn = 1.8V. Space factor = 0.2 δ = 1.8A /mm^2 Bm = 1wb/m^2

Data given

Q = 5kVA , F = 50Hz δ = 1.8A/mm^2

BM = 1 Wb/m^2 Ef = 1.8V Kw = 0.2

Core type, rectangular core , I phase long side = 2 x short size

Hw = 3Ww

IMAGE

Emf per turn $E_t = 4.4 \text{ f } \phi m$

$$\phi m = \frac{E_t}{4.4uf} = \frac{1.8}{4.u4\ \alpha\ 50} = 0.0081wb$$

Net are area $Ai = \frac{\phi m}{Bm} = \frac{0.0081}{1}\ 0.0081m^2$

Cross core area , Agi $\frac{Ai}{S_f} = \frac{0.0088}{0.9} = 0.0009m^2$

Cross section of core is rectangle Hence

Agi = length x breadth = a x b

Given =- a = 2b

Agi = 2b x b = $2b^2$

$$= \sqrt{\frac{\text{Agi}}{2}} = \sqrt{\frac{0.009}{2}} = 0.067m$$

b

a = 2b = 2x 0.067 = 0.134m

$Q = 2.22f \text{ Bm Ai Kw Aw f x } 10^{-3}$

$$A_w = \frac{Q}{2.22\ f\ B_m\ Ai\ K_w\ \delta\ x10^{-3}}$$

$$= \frac{5}{2.22 \text{ x } 50 \text{ x } 1 \text{ x } 0.0081 \text{ x } 0.2 \text{ x } 1.8 \text{ x} 10^6 \text{ x} 10^{-3}}$$

$= 0.0154m^2$

Window area Aw = Hw Ww

Hw = 3Ww

Aw = Hw Ww = 3Ww x Ww = $3Ww^2$

$$Ww = \sqrt{\frac{Aw}{3}} = \sqrt{\frac{0.0154}{3}} = 0.716m$$

Hw = 3Ww = 3 x 0.0716

= 0.2145m

The Net core area . Ai = $0.0081m^2$

Dimensation of the core a x b = 0.1314 x 0.067m

Window area Aw = $0.0154m^2$

Dimension of window , Hw x Ww = 0.2148 x 0.0716m

5. Estimate the main dimensions including winding conductor area of a 3 phase A- y core type transformer raped at 300kva, 6600/440V, 50Hz . A suitable core with 3 – steps having a circumscribing circle of 0.25m diameter and a leg spacing of 0.4m is available amf per turn = 8.5V s = $2.5A/mm^2$ Kw = 0.28 , sf = 0.9(Nov/Dec2017)

Data given

3- Phase A – y 50hz, Et = 8.5v 3- Stepped core, s = 2.5 A/mm^2 correct type 300Km , d = 0.25 Kw =- 0.28 leg Spacing = 0.4m sf = 0.9 6600/4400

Let 440v side be secondary

Vs = 440V/

Vp 6600V

Vs = $\frac{440}{3} = 254V$

Es Vs

Et = Es/Ts

Voltage ratio of transformer = $\frac{Vs}{Vp} = \frac{254}{6600}$

$$Tp = Ts \text{ x } \frac{Vp}{Vs} = 30 \text{ x } \frac{6600}{254}$$

= 779.5 N 780 turns

$$Q = \sqrt{3}\, VcpIlp \text{ x } 10^{-3}$$

$\sqrt{3}$ Vls Ils x 10^{-3}

$$Ilp = \frac{Q}{\sqrt{3}\, Vlp \text{ x } 10^{-3}}$$

$$Ilp = \frac{300}{\sqrt{3}\ 6600 \times 10^{-3}} = 26.24A$$

Since primary is delta connected phase current on primary side.

$$Ip = \frac{Ilp}{\sqrt{3}}$$

$$Ip = \frac{26.24}{\sqrt{3}} = 15.15\text{A}$$

$$ap = {Ip}/{\delta}\ \frac{393.65}{2.5} = 157.5\text{mm}^2$$

Copper area in window

Ac = 2[ap Tp + as Ts]

= 2[6.06 x 780 + 157.5 x 30]

18903.6 mm^2

Window Area $Aw = \frac{Ac}{Kw} = \frac{18903.6}{0.28}$

67512.86mm^2

67512.86 x 10^{-6} m^2

0.0675m^2

Area of circumscribing circle = $\frac{\lambda(0.25)^2}{4} = 0.049m^2$

For 3-stepped core

$$\frac{\text{cross core Area (Agi)}}{\text{Area of circumscribing}} = 0.84$$

Agi = 0.84 x $\tau d\ 2/4$

0.84 x 0.049 = 0.41m^2

Ai = Sf x Agi

= 0.9 x 0.041

$= 0.0369\ m^2$

$= 0.037\ \ x\ \ 10^6\ \ mm^2$

Given that leg spacing = 0.4m = Ww

Height of window Hw = $\frac{Aw}{Ww}$

$$\frac{0.0675}{0.45} = 0.15m$$

Number of primary turns/phase Tp = 780

Ni=umber of secondary turns/phase = Ts = 30

$ap = 6.06mm^2$

$as = 157.5mm^2$

$At = 0.0369\ m^2$

$Aw = 0.0675m^2$

Hw = 0.15m

Ww = 0.45m

6. Calculate the main dimensions and windings details of a 100KVA, 2000/400Volts, 50HZ, single phase shell type, oil immersed self cooled transformer. Assume Voltage per turns 10V flux density in core $1.1wb/m^2$, current density $2A/mm^2$ Window space factor = 0.33

The ratio of window height to window width and ratio of care depth o width of control limb = 2.5 the skading factor is 0.9.

$$Ai = \frac{Et}{4.44m\ \ f\ Bm} = \frac{10}{4.44\ x\,50\,x\,1-1}$$

$0.441m^2$

$$Agi\ = \frac{0.04095}{0.9}\ \frac{Ai}{Sf}$$

$0.0455m^2$

$$\frac{b}{2a} =\ \ 2.5$$

Agi = 2a x b

$2.5\ (2a)^2 = 0.0455$

$$(2a)^2 = \frac{0.0455}{2.5} = 0.0182$$

2a = 0.1349 0.135

Width of central limb = 2a = 2.5 x 0.135

Core depth = b = 2.5 x 2a = 2.5 x 0.135

= 0.3375m

The Yoke core half of the flux in the central limb. Assuming the same flux density in the core as in the limb the area of yoke is equal to half the area of the central limb

$$\text{Corss area of area Ay} = \frac{0.0455}{2}$$

$= 227.75 \times 10^{-3} m^2$

Depth of yoke Dy = b= 0.3375m

$$\text{Height of yoke Hy} =- \frac{22.275 \times 10^{-3}}{0.3375} = 0.0675m$$

IMAGE

The side limbs carry half of the flux in the central limb. Therefore the width of side limbs is half of the width of central limbs width of side a = 0.0675m

$Q = 0.22f\ Bm\ Kw\ f\ Af\ Aw \times 10^{-3}$

$100 = 2.22 \times 50 \times 1.11 \times 0.32 \times 2x\ 106 \times 0.041 \times Aw \times 10^{-3}$

$Aw = 0.0303\ m^2$

Hw Ww = 0.0303

$$\frac{Hw}{Ww} = 3$$

$3Ww^2 = 303 \times 10^{-4}$

Ww = 0.1m Hw = 0.3m

H = Hw + 2Hy = 0.3 + 2 x 0.0675

$= 0.435m$

$W = 2Ww = +4a = 2x0.1 + 4 \times 0.675$

$= 0.47m$

b- 0.3375m

H.V Winding turns = Tp $\frac{2000}{10} = 200$

L.V Winding turns = Ts = $\frac{400}{10} = 40$

H.V Winding Current = Ip = $\frac{100 \times 1000}{2000} = 50A$

H.V Winding conductor area = ap = $\frac{50}{2} = 25mm^2$

L.V Winding Current = Is = $\frac{100 \times 1000}{400} = 250A$

L.V Winding Area = as = $\frac{250}{2} = 125mm^2$

7. The tank of 1250 KVA, natural oil cooked transformer has the dimension length width and height as 0.62 x 1.55 x 1.85m respectively. The full load loss = 13.1Kw, loss dissipation due to redactions = $6w/m^{2o}c$ loss dissipation due to convection due to provision of tubes = 40% temperature rise = 40^oc. Length of each tube = 1m, diameter of tube = 50mm. Find the number of tubes for this transformer Neglect the top and bottom surface of the tank as regards the cooling

Data given:

KVA = 1250

Tank dimenastion = 0.65 x 1.55 x 1.85m

$l_1 = 1m$ $\lambda_{conv} = 6.5w/m^2 –C$

$dt = 50mm$ $\lambda_{red} = 6w / m^2 –C$

$\theta = 40^oc$. Improvement in cooling = 40%

Full load Loss = 13.1 Kw

L_T = Lenght = 0.65m

W_T = Width = 1.55m

HT = Height = 1.85m

Image

Heat dissipating surface of bank = Total Area of Vertical side

$S_t = 2\,[L_T\ H_T + W_T\ A_T]$

$2\ H_T\,[L_T + W_T]$

$2 \times 1.85 \times [0.65 + 1.55]$

$= 8.14\text{m}^2$

Loss dissipated by tank walls by rediation and convection = (6+6.5) S_t

= 12.5 S_t

Let heat dissipating area of tubs = XS_t

Loss dissipated by cooling tubes due to convection = 6.5 x $\frac{140}{100} x\,S_t$

= 9.1 $x\,S_t$

Total loss dissipated by tank and tubes - = 12.5 St + 9.1 $x\,S_t$

= St (12.5 + 9.1 x)

$$\left.\begin{array}{l}\text{Temperature rise in transformer} \\ \text{with cooling tubes}\end{array}\right\} \theta = \frac{\text{Total Loss}}{\text{Total Loss dissipated}}$$

Total loss = P_{cos} = 13.1 Kw = 13.1 x 10^3w

$$\theta = \frac{13.1 \text{ x} 10^3}{S + \left(12.5 + 9.(x)\right)}$$

$$12.5 + 9.1\,x = \frac{13.1\ x\ 10^{-3}}{\theta\ S_t}$$

$$\alpha = \frac{1}{9.1}\left[\frac{13.1 \text{ x } 10^{-3}}{\theta \, S_t} 12.5\right]$$

$$= \frac{1}{9.1}\left[\frac{13.1 \text{ x } 10^{3}}{40 \text{ x} 8.14} - 12.5\right] = 3.0476$$

Total Area of tubes = xst = 3.0476 x 8.14

= 24.8075 m^2

Total number of cooling tubes = $\frac{\text{Total Area of tubes}}{\text{Area of each tube}}$

Area of each tube = λ x 50 x 10^{-3} x 1 = 0.157m^2

Total number of cooling tubes $\frac{24.8075}{0.157} = 158$ tubes

The diameter of the tube is 50mm and the standard distance between the tube is half of the diameter and so let distance between tubs = 25mm.

The width of the bank is 1550mm. If we leave an edge spacing of 62.5mm on either sides then we can arrange 20 tubes width wise with a spacing of 75mm between centres of tubes on length we can arrange 8 tubes with same spacing as that of width wise tubes. But one row is not sufficient to accommodate the required 158 cooling tubes. Hence three rows of cooling tubes are provided on both length wise and width wise

The total number of tubes provided = 160

8. A 250 KVA . 660/440V 3-Phase core type transformer has a total loss of 48000 watts on full load the transformer bank is 1.255m in height and 1m x 0.5m in plan. Design a suitable scheme for cooling tubes if the average temperature rise i to be limited to 35ºC. The diameter of the tube is 50mm and are spaced 75mm form each other the average height of the tube is 1.05m(Nov/Dec2018,Nov/Dec2019)

Data given

KVA = 250 , θ = 35ºC , dt = 50mm

Lt= 1.05m Tank dimension = 0.5 x 1 x 1.25m

Total power loss = 4800W

Distance between tube centers = 75mm

6600/440V 3Phase Corev type

IMAGE

L_T = Lenght = 0.5m

W_T = Width = 1m

H_T = Height = 1.25m

$\left.\begin{matrix}\text{Heat dissiating} \\ \text{surface of tank}\end{matrix}\right\} S_t = \text{Total area of Vertical sides}$

$$= 2\,[L_T\ H_T + W_T\ H_T]$$

$$2\,H_T\,[L_T + W_T]$$

$$2 \times 1.25 \times [0.5 + 1] = 3.75m^2$$

Loss dissipated by tank walls by radiation and convection = $(6+6.5)\ S_t$

$$= 12.5\ S_t$$

Let heat dissipating area of tubs = XS_t

Loss dissipated by cooling tubes due to convection = $6.5 \times \frac{135}{100} x S_t$

$$= 8.775\ x S_t \ \underline{N\ 8.8}\ x S_t$$

Total loss dissipated by tank and tubes - = 12.5 St + 8.8 $x S_t$

$$= St\ (12.5 + 8.8\ x)$$

$\left.\begin{matrix}\text{Temperature rise in transformer} \\ \text{with cooling tubes}\end{matrix}\right\} \theta = \frac{\text{Total Loss}}{\text{Total Loss dissipated}}$

Total loss, P loss = 4800w

$$Q = \frac{4800}{St\,(12.5 + 8.8x)}$$

$$X = \frac{1}{8.8}\left[\frac{4800}{\theta S_t} - 12.5\right]$$

$$= \frac{1}{8.8}\left[\frac{4800}{35 \text{ x } 3.75} - 12.5\right]$$

$$= 2.7354$$

Total area of cooling tubes = x st = 2.7354 x 3.75

= $10.2578 m^2$

Area of each cooling tube = λ dr lt = λ x 50 x 10^{-3} x 1.05

= $0.1649 m^2$

$$\left.\begin{array}{l}\text{Number of}\\ \text{cooling tube}\end{array}\right\} n_t = \frac{\text{Total area of tubes}}{\text{Area of each tube}}$$

$$\frac{10.2578}{0.1649} = 62.206 \approx 62 \text{ tubes}$$

The width of the bank is 1000mm. If we leave an edge spacing of 87.5mm on either sides then we can arrange 12 tubes width wise with a spacing of 75mm between centres of tubes.

The Length of the bank is 500mm. If we leave an edge spacing of 100mm on either sides then we can arrange 5 tubes width wise with a spacing of 75mm between centres of tubes.

But one row is not sufficient to accommodate the required 62 cooling tubes. Hence 2 rows of cooling tubes are provided on both length wise and width wise

The total number of tubes provided = 64

They are arrange as 2 rows an widthwise each row of 12 and 11 tubes and 2 rows on length wise with each row consisting of 5 and 5 tubes.

9. Explain the different methods of cooling of Transformers(Apr/May2019)

The losses developed in the Transformers cores and windings are converted into thermal energy and cause heating of corresponding Transformers parts

The heat dissipation in temperature occurs by conditions convection and radiation

The paths of heat flow in Transformers

- Heat developed in core (or) ending to their outer surface in contact with the oil (conduction)

- From the outer surface of a Transformers parts to the oil that cools it (convection)
- From the oil to the wall of a cooler eg wall of tank (convection)
- Form the walls of the cooler to the cooling medium air -(or) water (radiation)

The various methods of cooling Transformers are

1. Air natural
2. Air
3. Oil natural
4. Oil natural – air forced
5. Oil natural water forced
6. Forced circulation of oil
7. Oil forced - water forced

The choice of cooling method depends upon the

Size

Type of application

Condition of the site

Natural cooling is suitable upto 10MVA the forced oil and oil air circulation are employed for Transformers of capacities 30mvA and upwards

The forced oil and water is used for Transformers designed for power plants

10. Explain briefly cores used in Transformers?

For core types Transformers the cross – section may be rectangular square (or) stepped

Circular coils are used for distribution Transformers

Square and stopped cores are used for power Transformers

For shell type rectangular cross section is used usually rectangular core is used for small and low voltage Transformers

In square core the diameter of the circumscribing circle is larger than the diameter of stepped core of same area of cross section thus when stepped core are used the length of mean turns of winging reduced with consequent reduction in both costs of copper and loss.

However with large number of steps a large number of different sizes of lamination have to be used this results in higher labour changes for shearing and assembling different types of laminations

Square core

IMAGE

D = diameter of circumscribing circle

(or)

a = Side of square

Diameter of circumscribing circle $d = \sqrt{a^2 + a^2}$

$$d = \sqrt{2a^2} = \sqrt{2}\ a$$

$$a = \frac{d}{\sqrt{2}}$$

Gross core area = Agi = a^2 $= \left(\frac{d}{\sqrt{2}}\right)^2$ = $0.5\ d^2$

Agi = $0.5\ d^2$

Sf = 0.9 stocking factor

Ai = Sf x Agi = 0.9 x $0.5\ d^2$

Ai = $0.45d^2$

Area of circumscribing circle = $\frac{\lambda}{4} d^2$

Ratio of area of core and circumscribing circle

Ratio	Square core	circumscribing circle	3- stepped core	4 –stepped core

$\frac{\text{Agi}}{\text{Area of circumscribing circle}}$	0.64	0.79	0.84	0.87
$\frac{\text{Ai}}{\text{Area of circumscribing circle}}$	0.85	0.71	0.75	0.78
Core Ara factor Kc = Ai/d^2	0.45	0.56	0.6	0.62

Unit-3

Design of DC Machines

PART – A

1. Write the expression for output coefficient of D.C machines

   Co = $\pi^2 \varphi Bgac * 10^{-3}$

2. Mention guiding factors for the selection of number of poles [NOV/DEC 2016]

   Factors to be considered for the selection of number of poles in d.c machine

   (i) Frequency
   (ii) Weight of iron parts
   (iii) Weight of copper
   (iv) Length of commentator
   (v) Labour charges
   (vi) Flash over and distraction of field form

3. What is meant by magnetic circuit calculation [MAY/JUNE 2016]

   The calculation of reductance, flux density and mmf for various sections of magnetic circuit are commonly referred to as magnetic circuit calculations

4. What are the factors to be considered in the design of Commutator of a D.C machine?
   - Peripheral speed
   - Number of coils in the armature
   - Number of brushes
   - Voltage between adjacent Commutator segment
   - Commutator losses

5. Write down the output equation of a d.c machine [MAY 2013]

   Output Equation of D.C machine = Po = Co $D^2 L_n Kw$

   Po = Power developed in armature of dc machine

   Co = Output coefficient

   Co = $\pi^2 \varphi Bavac * 10^{-3} Kw / m^3 ps$

6. Mention the factors governing the length of armature core in a d.c machine [NOV/DEC 2014]
   - Dimensions of the pole
   - Moment of inertia
   - Pheripheral speed
   - Voltage between adjacent Commutator segments

7. Mention the factor that, governing the choice of number of armature slots in a d.c machine

   The factor governing the choice of armature of armature slot are
   - Slot pitch
   - Slot loading
   - Flux pulsation
   - Commutation
   - Suitability for winding

8. Why square pole is preferred [MAY/JUNE 2015]

If the cross-section of the pole-body is square then the length of the mean turn of field winding is minimum. Hence to reduce the copper requirement a square cross-section is preferred for the poles of dc machine

9. Define copper space factor of coil [MAY/JUN2015]
   The copper space factor of a coil is defined as the ratio of conductor area and the area of cross-section of the coil.

   Copper Space Factor = $\frac{ConductorArea}{Areaofcross - \sec tionofthecoil}$

   Conductor Area = Number of turns * Area of cross – section of conductor

10. State the relation between the number of Commutator number of armature coils in a d.c generator
    The number of Commutator segment is equal to the number of coils in a d.c generator

    $$\beta_c = \frac{\lambda D_c}{C}$$

    β_c = Commutator segment pitch

    C = No of coils

    D_c = Diameter of Commutator

11. State the conditions of electrical armature windings electrical symmetry is achieved if the conductors are placed symmetrically with regard to the field systems. For this the number of slot and Commutator segments should be multiples of pair of pole

12. Discuss the parameters governing the length of Commutator
    The length of the Commutator depends upon the number of brushes and clearance between the brushes. The surface area required to dissipate the heat generated by the Commutator losses is provided by keeping sufficient length of Commutator

13. How the effects of armature reaction can be reduced?
    The effects of armature reaction can be reduced by
    - ❖ Increasing the length of air-gap at pole tips
    - ❖ Increasing the reductance at pole tips
    - ❖ Providing compensating winding and interpoles

14. What is the effect of interpole on main pole?
    In case of generator the interpole will magnetize the leading edge and demagnetize the trailing edge of main pole. In case of motor the interpoles will demagnetize the leading edge and magnetize the trailing edge of main pole.

15. How do design the number of brushes for a dc machine?
    The number of brush locations are decided by the type of winding. In lap-winding the number of brush locations is equal to number of poles and in wave winding it is always two.
    In each location there may be more than one brush mounted on a spindle, whenever the current per brush location is more than 70A. Hence the number of brushes in a spindle are selected such that each brush does not carry more than 70A

16. Calculate the output coefficient of a dc shunt generator from the given data.

    $B_g = 0.89 wh/m^2$, ac = 32000 amp.cond/m φ = 0.66

    Co = $\lambda^2 \varphi Bgac * 10^{-3}$

= λ^2 *0.66*0.89*32000*10^{-3}

=185.5 kw/ m^3 -ps

17. What are the factors to be considered for the choice of specific magnetic loading? And give the range

    The choice of specific magnetic loading depends on the following

    - Flux density in teeth
    - Frequency of flux reversals
    - Size of machine

      Range of specific magnetic loading in d.c machine is = 0.4 to 0.8 wh/m^2

18. What are the factors to be considered for the choice of specific electric loading? And give the range.

    The choice of specific electric loading depends on the following.

    - Temperature rise
    - Speed of machine
    - Voltage
    - Size of machine
    - Armature reaction
    - Commutation

      Range of specific Electric loading = 15000 to 50000 amp.cord/m

19. What are the factors to be considered for estimating the length of air-gap in d.c machine

    The factors to be considered for estimating the length of air-gap are

    - Armature reaction
    - Cooling
    - Iron losses
    - Distertion of field form and noise

20. State any three conditions in deciding the choice of number of slots for a large dc machine

    - The slot loading should be less than 1500 ampere conductors
    - The number of slot per pole should be greater the (or) equal to 9 to avoid sparking
    - The slot pitch should be between 25 to 35mm

21. Explain how depth of armature core for a dc machine is determined

$$\phi_c = \frac{\phi}{2}, \; A_c = \frac{\phi_c}{B_c} = \frac{\phi}{2B_c}$$

$$A_c = L_i d_c$$

$$L_i d_c = \frac{\phi}{2B_c}$$

$$d_c = \frac{\phi}{L_i 2B_c}$$

ϕ =Flux per pole

ϕ_c = Flux in armature core

B_c =Flux density in armature core

L_i =Net iron length of armature

=Depth of armature core

mb=Area of cross-section of armature core

PART-B

1. Explain the procedure for the selection of number of poles in d.c machine[NOV/DEC2-16]

The number of poles used in D.c machines has an important bearing upon the magnetic and electric circuits. The selection of number of poles depends on

(i) The frequency should lie between 25 t0 50 Hz

(ii) The value of current per parallel path is limited to 200 ampc. Thus the current per brush arm should not be more than 400mps

Current per parallel path = $\frac{I_a}{p}$ lap winding

$= \frac{I_a}{2}$ for lap winding

Current per brush arm = $2\frac{I_a}{p}$ lap winding

$= I_a$ lap winding

P=number of poles

(iii) The armature mmf should not be too large. The normal values of armature mmf per pole

Armature mmf per pole

Output in KW	Armature mmf per pole in AT
Upto 100 100 to 500 500 to 1500 Over 1500	5000 (or) less 5000 to 7500 7500 to 10000 Upto 12500

(iv) If there are more than one choice for ch of poles which satisfies the above three conditions, then choose the largest value for poles. This results in reduction in iron and copper

- By increasing the number of poles, the weight iron in the armature core can be decreased
- The overall diameter of the machine decreases as the number of poles is increased.
- The use of large number of pole in increased danger of flash over between adjacent brush arms
- With the increase in number of poles labor charges will increase
- With the increase in number of poles there is reduction in distortion of field from under load conditions

2. For a preliminary design of a 50 Hp, 230v, 1400 rpm, dc shunt motor. Calculate the armature diameter and core length, number of poles and peripheral speed. Take Bav = 0.5 wh/sq.m ar/m = 25000 efficiency = 0.9[Nov/Dec 2016]

Solution:-

$\frac{o}{p} = 50Hp$, v = 230v , N = 1400rpm, Bav = 0.5 wb/sq.m, ac/m = 25000, η = 0.9

Power input = Pi = P/η = $\frac{50*0.746}{0.9}$

41.44KW

Also power input Pi = VI*10^{-3}

I = $\frac{Pi}{V*10^{-3}}$ = $\frac{41.44}{230*10^{-3}}$

= 180.17A

Armature current = Ia = I = 180.17A

Since the armature current is less than 200A, the current per parallel path will not exceed the upper limit 200A

Let, P = 2, f = $\frac{PW}{120}$ = $\frac{2*1400}{120}$ = 23.33 Hz

P = 4, f = $\frac{4*1400}{120}$ = 46.66 Hz

P = 6, f = $\frac{6*1400}{120}$ = 70

The frequency of flux reversals should lie in the range of 25 to 50 Hz. For minimum cost the highest possible choice of poles should be choosen.

Hence the number of poles P = 4

Output coefficient Co = λ^2 Bav ac*10^{-3}

= λ^2 * 0.5 * 25000*10^{-3}

= 123.370 KW/m^3 nps

For dc motor, power developed in armature = Pa □ P = 50*0.726 = 37.3 KW

Pa = co D^2 Ln

M

= $\frac{Pa}{C_o n}$ = $\frac{37.3KW}{123.370*(\frac{1400}{60})}$

$\frac{37.3}{2878.633}$ = 0.01296 m^3

Let us assume a square pole face for a square pole face $\frac{L}{c} = 0.7$

L = 0.7c = 0.7 $\frac{\lambda D}{p}$ = $\frac{0.7*\lambda}{4}$ D

L = 0.5498D

D^2 L= 0.01296

D^2 (0.5498D) = 0.01296

$D^3 = \frac{0.01296}{0.5498}$

D = $3\sqrt{\frac{0.01296}{0.5498}}$ = 0.2867m

Va = λD_n

= λ *0.2867* $\frac{1400}{60}$

= 21.016 m^3

L = 0.1576m P =4

D = 0.2867m

Va = 21.016 m^3

3. Explain the various steps involved in the design of shrunk field winding of dc machine

(I) Determine the dimensions of the pole. Assume suitable value of leakage coefficient form leakage co efficient table and flux density in the range 1.2 to 1.7 wb/m^2

flux in the pole body Pp = cr ϕ

Area of pole body = $\frac{\phi P}{\beta P}$

for cylindrical pole

Diameter of pole body dp= $\sqrt{\frac{4Ap}{\lambda}}$

for rectangular pole

Length of pole Lp = L - 10.00/to 0.015

Net iron length of pole Lpi = 0.9Lp

Width of the pole bp $\frac{Ap}{Lpi}$

(ii) Determine the length of mean turn of Field coil. Assume a suitable depth of field winding from (Depth of field winding table)

for rectangular field coils

Length of mean tune Lmt = 2 Lp + bp + 2df

For cylindrical field colis

Length mean turn

Lmt = λ (dp + df)

(iii) Calculate the voltage across each shunt field coil voltage across filed coil

$$Ef = \frac{(0.8 \; to \; 0.85)}{P}$$

(iv) calculate the area of cross - section of field conductor. Area of cross section of filed conductor of = $Ef = \frac{eLmtAIfe}{E_f}$

(v) Calculate the diameter of field conductor and copper space factor

Diameter of field conductor including thickness = Fci = dfc + thickness of insulation

copper space facotor, Sf = 0.75 $\left[\frac{dfc}{dfei}\right]^2$

(vi) Determine the number of turns (Tf) and height of field coil (hf)

2 Lmt (h+df) = $\frac{Ef^2 af}{e \; Lmt \; Tf}$

Tf af = Sf hf df

(vii) Calculate the resistance of the filed coil and field current.

Resistance of field copil Rf = $Ef = \frac{T_f eLmt}{a_f}$

field current $I_f = \frac{E_f}{R_f}$

(viii) check for current density in filed coil.

current density in field coil $I_f = \frac{E_f}{R_f}$

the current density should not exceed 305 A/ mm2. If it exceeds 3.5A/m^2 Then increase of by 5% and repeat steps 5 to 8 unit Ff is less than 3.5 A/m^2

(ix) Check for desired value of Actual value of mmf . At actual = I_f T_f the desired filed mmf may be either specified in the problem (or) may be taken or 1.1 to 2.5 times the armature values of nmf should be equal to (or) higher than desired values

If the actual mmf is less than the desired values then increase the dy, of filed winding by 5% and repeat step - 2 to step -9 until the desired mmf is achieved

(x) check for temperature risk Actual copper loss = If Rf

The surface area of field coil S = 2(mt, (h_f fd_f))

cooling coefficient C = $\frac{0.14 \text{ to } 0.16}{1 + 0.1\,Va}$

V_a = Peripheral velocity of armature

Temperature rise $\theta m = \frac{\text{Actual copper x c}}{S}$

If temperature rise is within limit then the design is accepted. the allowable temperature rise depends on the class of inculcation . if the temperature rise exceeds on the limit than repeat the design by increasing the depth of field winding by 5%.

4. Determine the diameter and length of a armature core of 55 Kw 110V, 1000rpm, 4 pole shunk generator assuming specific electric and magnetic loadings 26000amps con/m and 0.5 wb/m^2 respectively the

Data given

55 Kw, 110V, 4 pole, shunt generator Bav = 0.5 wb/m^2 N = 1000 rpm, ac = 26000 amp.cond/m, if = 10A, b = 0.7Z, Ia Pa = 4 volts, L = 1.1b.

Solution :

Induced emf,

E = V+IaPa = 110+4 = 114 volts

Load current I = $\frac{P}{Vx10^{-3}}$

= $\frac{55}{110 \text{ x } 10^{-3}}$ = 500A

Ia = I+If = 500 + 10 = 510A

Pa = EIa x 10^{-3}

= 114 + 510 x 10^{-3} = 58-14Kw

$Co = \lambda^2\ Bav\ ac \text{ x} 10^{-3}$

$= \lambda^2 \text{x}\, 0.5 \text{ x } 26000 \text{ x} 10^{-2}$

$= 18.3 Kw / m^2\ ps$

Power developed in amateur Pa = CoD^2Ln

$$D^2L = \frac{Pa}{Con} = \frac{58.14}{128.3\,\text{x}\left(1000/60\right)}$$

$$= 0.0272\,m^3$$

L =1.1b. b= 0.7τ

L =1.1b = $1.1\left(0.7\tau\right) = 0.77\tau$

$$= 0.77\,\text{x}\,\frac{\lambda}{P}$$

$$= \frac{0.72\,\text{x}\,\lambda}{4} D = 0.6048D$$

$L = 0.6048D$. $D^2L = 0.0272$

D2 (0.6048 D)=0.0272

$$\text{D} = \left[\frac{0.0272}{0.6048}\right]^{1/3} = 0.356m$$

L = 0.6048D = 0.6048 x 0.356 = 0.215m

The armature current , Ia = 510A

If wav winding is used turn

Current per parallel palm = Ia/2

Hence Lap winding is used,

Specific magnetic loading Bav = $\frac{P\phi}{\lambda DL}$

Flux pa pole ϕ = $\frac{Bav\lambda DL}{P}$

$$= \frac{0.5\times\lambda\times0.355\times0.215}{4}$$

= 0.03wb

Lap winding is used E = $\frac{\phi 2w}{60}$

Number of armature conditions 2 = $\frac{60\times E}{\phi \text{N}}$

$$= \frac{60 \times 114}{0.03 \times 1000} = 228$$

Cfss lie in the range of 25 to 35mm

Number of armature slobs, 5a $= \frac{\lambda D}{ysa}$

Yss = 25mm , Sa $= \frac{\lambda \times 0.356}{25 \times 10^{-3}} = 45$

Yss = 35mm $\frac{\lambda \times 0.356}{35 \times 10^{-3}} = 32$

The number of slots should lie in the range 32 to 45. for lap winding slops per pole should be multiple of pole pair. Here pole pair = 2

Hence number of slots should be even number allowable choice of slots are 32, 34, 36, 38, 40, 42, and 44. To reduce flux pulsation the slots per pole should be integer I 1/2.

Lets slots per pole = 9I1/2 = 8.5 (or) 9.5

Let us choose 9.5 slots per pole

Number of slots = slots per pole x number of poles

9.5 x 4 = 38 slots

The designed value of 38 slots is one of the allowed choice of slots> hence the choice of 38 slots is acceptable

Conductor per slots = $\frac{Z}{Ss} = \frac{228}{38} = 6$

(For double layer winding conductors per slot should be even)

Minimum Number off coils

C_{min} $\frac{EP}{15} = \frac{114 \times 4}{15} = 30$

Number of coils, c = 1/2 = $\times$ 4Sa

Let us assume different values of coils sides per slots , u

u = ,, C = 1/2 x 2 x 38 = 38

u = 4, = 1/2 x 4 x 38 = 76

Choose the number of coils such that the conductor per slots is divisible by coils sides per slots. Here to is divisible by 2. Hence the best choice for number of coils is 38

Solution:

Number of slots = 38

Number of coils = 38

Conductors per slots = 6

Total armature conductors

Z = slots x conductors /slots

= 38 x 6 == 228

Number of turn per coils = $\frac{2}{2c} = \frac{228}{2 \text{ x } 38} = 3$

D = 0.356m

L = 0.215m

S_a = 38

C = 38

Z = 228

Conductors /slots = 6

Turn /coil = 3

5. A5KW 250 Voltas and pole 1500pm dc shunt generators is designed to have a square pole face. The average magnetic flux density in the air gap is 0.42 wb/m^2 and ampere conductors per meter = 15000. Compute the main dimension of the machine. Assume full load efficiency = 87%. The repair of pole are to pole pitch = 0.06 [May/June 2015]

Data given:

5Kw, 250V , 4pole, N = 1500vpm Bav = 0.42wb/m^2,ac = 15000 amp cad/m D = 87% L/T = 0.06

Solution:

Power developed in armature = Pa = $\frac{p}{\eta} = \frac{5}{0.87} = 8.74\,Kw$

Output coefficient = Co = λ^2 Bw ac x 10^{-3}

Co = $\lambda^2 \times 0.42 \times 15000 \times 10^{-3}$

= 62.178 KW/m^2-rps

Pa = Co D^2LA

$$D^2L = \frac{Pa}{Co\cap} = \frac{5.74}{62.178 \times 1500/60} = \frac{5.74}{1554.45}$$

= 0.00369

L/C = 0.06

L = $\varsigma \times 0.06$

$$\frac{\lambda P}{P} \times 0.06 = \frac{\lambda \times 0.06}{4} \times D = 0.0471D$$

D^2L = 0.00369

D^2 [0.0471D] = 0.00369

$0.0471D^3$ = 0.00369

$$D = \sqrt{\frac{0.00369}{0.471}} = 0.42789m$$

L = 0.0471 x 0.4278 = 0.0201m

6 .Out put equation of a D.C machine

Induced emf in armature = E = $\frac{\phi 2N}{60}$ x $\frac{P}{a}$

$$E = \frac{\phi 2 \cap P}{a}$$

In the armature of d.c machine the conductors are connected in parallel paths then the currnt through each conuctors I_z = $\frac{Ia}{a} = Ia = aIz$

Specific magnetic loading = Bav = $\frac{P\phi}{\lambda DC}$

$$P\phi = \text{Bav} \times \lambda DL$$

Specific electric loading

$$ac = \frac{I_2 Z}{\lambda D}$$

$$I_2 Z = ac \times \lambda D$$

power developed in armature Pa = EIa x 10^{-3} Kw

$$Pa = \frac{\phi 2Ap}{a} \text{ x Ia x} 10^{-3}\text{Kw}$$

$$= \frac{\phi 2Ap}{a} \text{ x I2 x} 10^{-3}\text{Kw}$$

$$= I_2 \text{ Z P} \phi \text{ x} \cap 10^{-3} \text{ kw}$$

$$= I_2 \text{ZBw} \lambda DL \text{ x} \cap \text{ x10-3Kw}$$

$$= ac\lambda \cap Bav\,\lambda DL \text{ x n x} 10^{-3} kw$$

$$= \lambda^2 D^2 \text{ L} \times ac \times Bav \times \cap \times 10^{-3} Kw$$

$$= \lambda^2 \times Bav \times ac \times 10^{-3} Kw \times D^2 L \cap$$

co D^2Ln

$$Co = \lambda^2 \times Bav\, ac \times 10^{-3}$$

Co = output coefficient

7. Calculate the diameter and length of armature for 7.5KW 4 pole 1000rpm, 220V shunt motor. Given full load efficiency =0 83 maximum gap flux density = 0.9 wb/m^2. Specific electric loading = 30.000 ampere conductor/metric field fam factor = 0.7. Assume that the maximum efficiency occurs at full load and the field current is 2.5% of raped current the pole is square. [May 2013]

Data Given:

P_o = 7.5Kw, P = 4 n == 1000rpm V =- 220v, η = 0.82 , Bg = 0.9wb/m^2

ac = 30,000 amp load/m , Kf = 0.7 If = 25% of rated current.

Power input = $\frac{P}{\eta} = \frac{7.5 \times 10^3}{0.83} = 9040w$

Total Losses at full - load = 9040 - 7500 = 1540w

Since the maximum efficiency at full load the constant and armature I^2p loss are equal at full load.

constant losses = $\frac{1540}{2} = 770w$

Motor current at full local = $\frac{7500}{0.83 \times 220} = 41.1A$

field current = 0.025 x 41.1 = 0.03A

field and wind age plusion loss = 770-227 = 543w

Power developed by a armature -pa = 7.5 + 0.543 = 8.1 Kw

Bav = KffBg = 0.7 x 0.9

= 0.63 wb/m^2

Co = λ^2 x 0.63 x 30,000 x 10^{-3}

= 186.5

$\cap = \frac{1000}{60} = 16.67\ rps$

$D^2L \frac{Pa}{co\cap} = \frac{8.1}{186.3 \times 16.67} = 2.6 \times 10^{-3} m^3$

for square pole face

$\frac{L}{\psi t} = 1$

L = 0.7 x $\frac{\lambda D}{4}$

= 0.55D

$0.55D^3$ = 2.61 x 10^{-3}

D = 0.17m

L= 0.09m

8. Explain various steps involved in the design of armature winding of DC machine [May - 2014]

Steps for design of lap winding for a dc machine

(i) find te range of slots form the RANGE OF SLOTS PITCH. armature slots pitch YSA = 25 to 35mm. slots, sa = λD /ysa , where D is diameter of armature.

(ii) In the above range of clots, list the values of slots which are multiples of pole pairs.

(iii) In order to reduce thus pulsations, the slots per pole should be an integer I Y2 the integer should be in the range of 8 to 16 list all the multiples of integer 1/2 from the list obtained in step 2

(iv) Choose the suitable slots from the list obtained in step 3

(v) Estimate the total number of armature conductor, Z using the equation of induced emf,m E = ϕ2n p/a. Find the conductors per slots and choose in to the nearest even number.

Conductors per slots = 2/w

(vi) Find the minimum number of coils Ep/15

(vii) Assume , u = 2,4,6,8,…..act where u = coils sides per slots

(viii) For each value of u calculate the number omf coils, C= = 1/2, S, choose the number of coils such that it is greater than minimum number of coils. Also the values of u corresponding to choose values of C should be a division of conductors per slots

(ix) Once the number of coils and slots are finalised. estimate the new values of odd number of conductors and number of turns per coil. Total armature conductors, 2 = slots x conductors per slots number of turn per coil = 2/2c

If a suitable value of c is slots obtained to satisfy the above conditions. then make another choice of slots from the list obtained in step 3.

9. Find the minimum number of poles for a 1200 Kw generator if the arrange voltage between Commutator systems is not to exceed 15 and the armature mmf per pole is not be exceed 10,000A.

Solution:

For simplex lap (or) wave winding, average voltage between adjacent segments

$$Ec = \frac{EP}{C}$$

Voltage of , machine $E = \frac{C\,EP}{C}$

Taking single turn coil total number of coils in the machine

$$C = \frac{Z}{2} \quad E = \frac{2Ec}{2P}$$

P = EIa x 10^{-3} Kw = $\frac{Z\,Ec}{2p}$ Ia x 10^{-3}

armature mmf paer pole $ATa = \frac{Ia}{a} . \frac{Z}{2p}$

$$\frac{IaZ}{2p} = a\mathrm{AT}a$$

P = aATa Ec x 10^{-3}

Minimum number of paralel path = a $\frac{P \text{ x } 10^3}{ATaEa}$

$$\frac{1200 \times 10^3}{10,000 \times 15} = 8$$

These parallel paths can be obtained by using a simplex lap winding with poles

Minimum number of poles = 8

10. Design of Interpoles

The interpoles are small poles placed between main poles. The polarity of the main pole just ahead for a generator and just behind it for a motor in the direction of rotation

The winding of the interpole must produce an mmf which is sufficient to naturalize the cross magnetizing armature mmf of interpoler axis and enough more to produce the flux density requried to generate rotational voltage in the coil undergoing commutation to cancle the reactance voltage.

Since both the armature reaction and reactance voltage are proportional to armature current the interpole winding should be connected in series with the armature for production of rectaxtizing effect at all condition of load.

Average reactance voltage in the coil = $2T_c$ ac Va >L

T_c = Turns per (oil)

ac = Specific electric loading

Va = Peripheral speed of armature

L = Length of armature

λ = Specific per menace

The inductance of a coil in armature = 2TcL2

The interpoles are made of

Normally the length of interpole is made equal to length of main pole.

Bgi = Flux dendity under inter pole

$$Bgi = ac\,\lambda \frac{L}{Li\delta}$$

Lip = Length of inter pole

$$Bgi = 2I_2Z_s \frac{L}{LiP}\frac{1}{V_aT_c}$$

Zs = conductor per slots

lgi = Length of air gap under the interpole

Kgi = Interpole gap contraction factors

Ati - mmf required for interpole

Ati = mmf required to establish zgi + mmf required to overcome armature reaction

mmf required to establish bgi = 80,000 bgi

$$\left.\begin{array}{l}\text{mmf requried to}\\ \text{overcome amature}\\ \text{reaction}\end{array}\right\} = \frac{I_2 2}{2P}\ (\text{without compensation winding})$$

$$\frac{(1-4)\ I_2Z}{2p}\quad \text{(with compensation winding)}$$

Number of turns in interpole = ATi/ In

Current density in interpole winding = $\delta I = 2.5$ to $4A/mm^2$

Area if cross section of interpole conductor = $Ia / \delta i$