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**DC Generators**

**المحاضرة السابعة و السادسة والخامسة**

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| **Week****5 ,6,7** | **Losses in DC machines****Power Stages and Efficiency** |

**اعداد**

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**Losses in DC machines**

In a practical machine, whole of the input power cannot be converted into output power as some power is lost in the conversion process. This causes the **efficiency of the machine** to be reduced. Efficiency is the ratio of output power to the input power. Thus, in order to design rotating dc machines (or any electrical machine) with higher efficiency, it is important to study the losses occurring in them. **Various losses in a rotating DC machine (DC generator or DC motor)** can be characterized as in fig 4.

**Copper losses**

These losses occur in [armature](https://www.electricaleasy.com/2012/12/armature-winding-of-dc-machine.html) and field copper windings. Copper losses consist of Armature copper loss, Field copper loss and loss due to brush contact resistance.

**Armature copper loss** =$ I\_{a}^{2}R\_{a}$  (where, $I\_{a} $ = Armature current and $R\_{a}$ = Armature resistance).

This loss contributes about 30 to 40% to full load losses. The armature copper loss is variable and depends upon the amount of loading of the machine.

**Field copper loss in shunt winding** = $I\_{sh}^{2}R\_{sh}$.

**Field copper loss in series winding** = $I\_{se}^{2}R\_{se}$.

Fig 4. Losses in DC Machine.

**Brush contact resistance** also contributes to the copper losses. Generally, this loss is included into armature copper loss.

**Iron losses (Core losses)**

As the armature core is made of iron and it rotates in a magnetic field, a small current gets induced in the core itself too. Due to this current, **eddy current loss** and **hysteresis loss** occur in the armature iron core. Iron losses are also called as **Core losses or magnetic losses.**

**Hysteresis loss:**  Wh ∝ (B 1.6 max) f.

**Eddy current loss**: We ∝ (B2 max) f2.

Mechanical losses consist of the losses due to friction in bearings and commutator. Air friction loss of rotating armature also contributes to these. These losses are about 10 to 20% of full load losses. Iron and mechanical losses are collectively known as **Stray (Rotational) losses Wco.**

**Power Stages and Efficiency**

Various power stages in the case of a d.c. generator are shown below:



Fig 5. Power stages in DC machine.

Following are the three generator efficiencies :

1. **Mechanical Efficiency:**

|  |  |
| --- | --- |
| $$η\_{m}=\frac{B}{A}=\frac{total watts generated in armature}{mechanical power supplied}=\frac{Eg I\_{a}}{output of driving engine}$$ | (7) |

1. **Electrical Efficiency:**

|  |  |
| --- | --- |
| $$η\_{e}=\frac{C}{B}=\frac{watts available in load circuit}{total watts generated}=\frac{VI}{Eg I\_{a}}$$ | (8) |

1. **Overall or Commercial Efficiency:**

|  |  |
| --- | --- |
| $$η\_{c}=\frac{C}{A}=\frac{watts available in load circuit}{mechanical power supplied}$$ | (9) |

It is obvious that overall efficiency $η\_{c}=η\_{m}×η\_{e}$. For good generators, its value may be as high as 95%.

**Condition for Maximum Efficiency**

The maximum Efficiency in DC Shunt generator can be evaluated as follows:-

|  |  |
| --- | --- |
| $$Generator output (at load) = VI$$ | (9) |
| $$Generator input = output + losses $$$$= VI + I\_{a}^{2}R\_{a}+ W\_{co}= VI + (I + I\_{sh})^{2}R\_{a} +W\_{co}$$ | (10) |

However, if $I\_{sh}$is negligible as compared to load current, then $I\_{a}$= *I* (approx.)

|  |  |
| --- | --- |
| $$η=\frac{Output}{Input}=\frac{VI}{ VI + I^{2}R\_{a}+ W\_{co}}=\frac{1}{1+\left(\frac{IR\_{a} }{V}+\frac{W\_{co}}{VI}\right)}$$ | (11) |

Now, efficiency is maximum when denominator is minimum i.e. when

$$\frac{d}{dI}\left(\frac{IR\_{a} }{V}+\frac{W\_{co}}{VI}\right)=0$$

Which leads to the following conclusion:-

|  |  |
| --- | --- |
| $$I^{2}Ra = W\_{co}$$ | (12) |

**Example 4:** A 10 kW, 250 V, d.c., 6-pole shunt generator runs at 1000 r.p.m. when delivering full-load. The armature has 534 lap-connected conductors. Full-load Cu loss is 0.64 kW. The total brush drop is 2 volt. Determine the flux per pole. Neglect shunt current.

**Solution**

Since shunt current is negligible, there is no shunt Cu loss. The copper loss occurs in armature only.

$$I=I\_{a}=\frac{10,000}{250}=40 A$$

$$Armature losses=I\_{a}^{2}R\_{a}⟹ 40^{2}×R\_{a}= 0.64×10^{3} ⟹ R\_{a}=0.4 Ω$$

$I\_{a}R\_{a}$= 0.4 $×$ 40 = **16 V;** Brush drop = **2 V**

∴ Generated e.m.f. $Eg$= 250 + 16 + 2 **= 268 V**

$$Eg=\frac{Z P ∅ N}{A 60}⟹ 268=\frac{∅×534×1000}{60} $$

$$∅=30 ×10^{-3} Wb=30 mWb$$

**Example 4:** A shunt generator delivers 195 A , 250 V. The armature resistance and shunt field resistance are 0.02 Ω and 50 Ω respectively. The iron and friction losses equal 950 W. Find **(a)** E.M.F. generated **(b)** Cu losses **(c)** output of the prime motor **(d)** commercial, mechanical and electrical efficiencies.

**Solution**

1. $I\_{sh}$ $= 250/50 = 5 A, I\_{a}=195 +5=200 A.$

Armature voltage drop = $I\_{a}R\_{a}=200×0.02=4 V$***.***

∴ Generated e.m.f. = 250 + 4 = **254 V**

**(*b*)** Armature Cu loss = $I\_{a}^{2}R\_{a}=200^{2}×0.02=800 W$

Shunt Cu loss = $VI\_{sh} = 250 ×5 = 1250 W$

∴ Total Cu loss = 1250 + 800 = **2050 W**

**(*c*)** Stray losses = **950 W** ; Total losses = 2050 + 950 = **3000 W**

Output = *V I* = 250 $×$ 195 = **48750 W** ; Input = 48750 + 3000 = **51750 W**

∴ Output of prime mover = **51,750 W**

**(*d*)** Generator input = **51750 W** ; Stray losses = **950 W**

Electrical power produced in armature = 51750 − 950 = **50800 W**

$$η\_{m}=\frac{total watts generated in armature}{mechanical power supplied}=\left(\frac{50800}{51750}\right)×100=98.2\%$$

Electrical or Cu losses = **2050 W**

$$η\_{e}=\frac{watts available in load circuit}{total watts generated}=\frac{48750}{48750+2050}×100=95.9\%$$

$$η\_{c}=η\_{m}×η\_{e}=94.2\%$$

**Example 4:** A shunt generator has a Full Load current of 196 A at 220 V. The stray losses are 720 W and the shunt field coil resistance is 55 Ω. If it has a Full Load efficiency of 88%, find the armature resistance. Also, find the load current corresponding to maximum efficiency.

**Solution**

Output (load) = 220 $×$ 196 = **43120 W** ; ηe = **88%**

Electrical input = ${43120}/{0.88}$ = **49000 W**

Total losses = 49000 − 43120 = **5880 W**

Shunt field current = ${220}/{55}=4 A$

∴ $I\_{a}$= 196 + 4 = **200 A**

∴ Shunt Cu loss = 220 $×$ 4 = **880 W** ; Stray losses = **720 W**

Constant losses = 880 + 720 = **1600 W**

∴ Armature Cu loss = 5880 − 1600 = **4280 W**

∴ $I\_{a}^{2}R\_{a}=4280 W ⟹ R\_{a}=0.107 Ω$

For maximum efficiency,

$I\_{a}^{2}R\_{a}$= constant losses = 1600 W $⟹$ *I* =$\sqrt{{1600}/{0.107}}=122.34 A$ .