



ELECTRICAL MACHINES II

EPMN304

Course Grading System

2

100 Marks

40

Final Exam

60

Semester Work

- **20 Mid-term**
- **15 Quizzes**
- **12 Assignments**
- **8 Self Study Report**
 - **10 Labs**

Course Schedule

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- Lecture: Sunday 9 – 11 am ()
- Tutorial: Monday 2 - 5 pm ()
- Office Hours: Tuesday & Wednesday 11-12
- Quizzes: W4–W6–W10–W12 + After Every Online Lecture & Tutorial
- Assignments: W3 – W5-W11-W13
- Labs: W7 – W9- W11
- Mid-term: W8
- Email: tamermabdo@eng.cu.edu.eg
- Google Classroom code:
- Scholar Page: <https://goo.gl/JDVOPR>

Course Learning Outcomes (LOs)

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1. **Explain the magnetic field distribution and voltage induction in induction and synchronous machines.**
2. **Describe the theory of operation of induction machines.**
3. **Discuss the theory of operation of synchronous machines.**
4. **Calculate the induction motors performance characteristics using the equivalent circuit model.**
5. **Analyze the effect of changing different parameters of the induction motor on its performance and design.**
6. **Apply the exact phasor diagram and the equivalent circuit models of the synchronous machines.**
7. **Differentiate between the synchronous generator performance at stand-alone and grid-connected conditions.**
8. **Analyze the performance and applications of synchronous motors.**
9. **Experiment induction machines to calculate the equivalent circuit parameters and examine its performance.**
10. **Experiment synchronous generator to determine the different machine characteristics.**
11. **Develop systematic thinking skills to solve general problems and identify critical factors.**

Course Contents

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- AC Machines Fundamentals
- Three-phase Induction Motors
 1. Principle of operation.
 2. Equivalent circuit and power flow.
 3. Torque-speed characteristics.
 4. Starting.
 5. Testing.

Course Contents

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- Single-phase Induction Motor
- Synchronous Generators
 1. Construction and types.
 2. Operation of stand-alone generators.
 3. Parallel operation.
 4. Testing

Course References

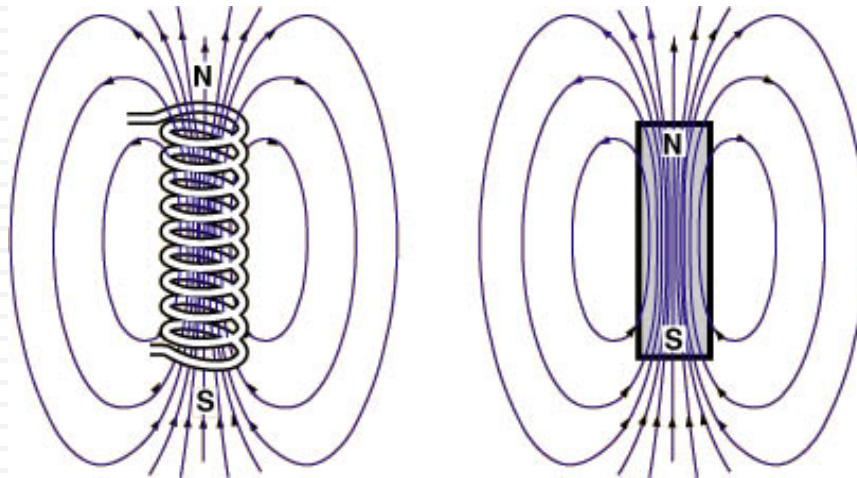
7

- A.E. Fitzgerald & Charles Kingsley, *Electric Machinery*, 7th Edition.
- Stephan J. Chapman, *Electric Machinery Fundamentals*, 5th Edition.

Introduction: Ampere's Law

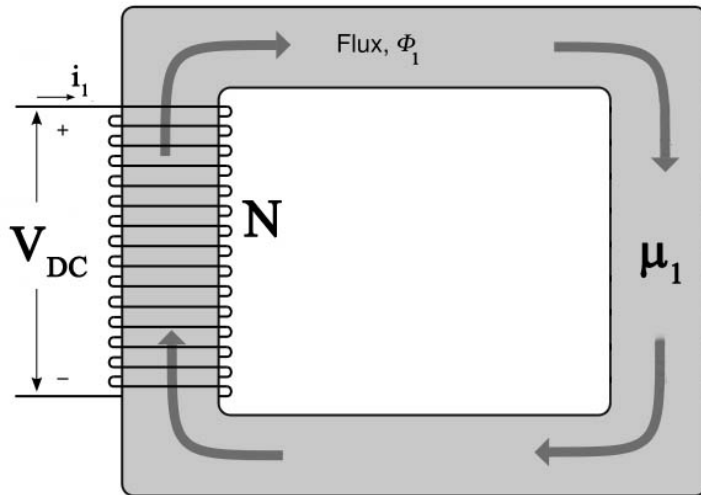
8

$$\oint_c \underline{H} \cdot \underline{dl} = \int_S \underline{J} \cdot \underline{dS} = I_{en}$$

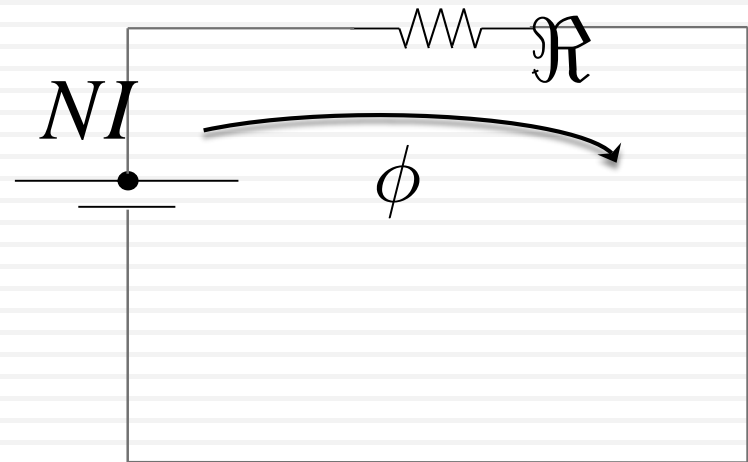


Introduction: Magnetic Circuits

9



$$NI = \phi \mathcal{R}$$



$$\mathcal{R} = \frac{l_{mc}}{\mu A}$$

Reluctance

Introduction: Faraday's Law

10

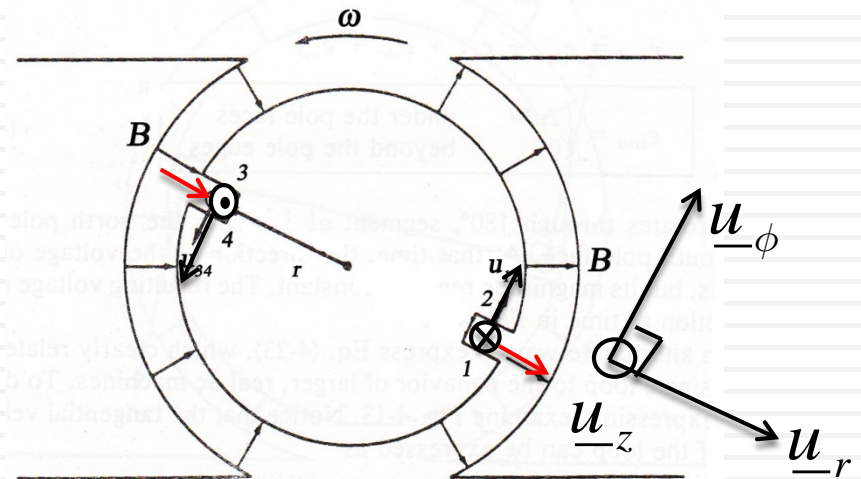
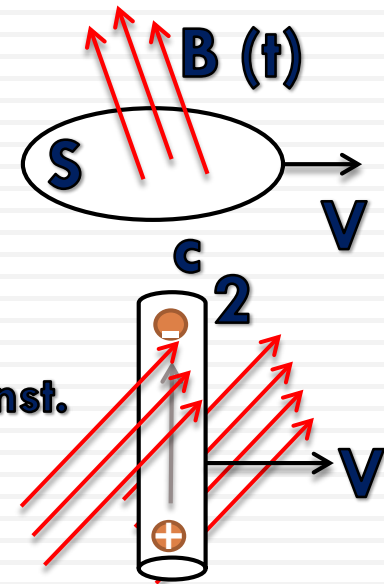
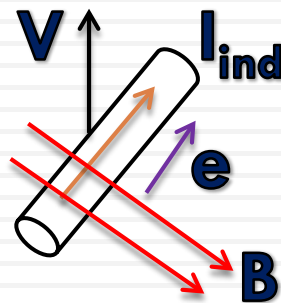
$$emf = -\frac{d\lambda}{dt}$$

$$\lambda = N\phi$$

$$\phi = \int_S \underline{B} \cdot \underline{dS}$$

$$e_{21} = \int_1^2 \underline{v} \times \underline{B} \cdot \underline{dl}$$

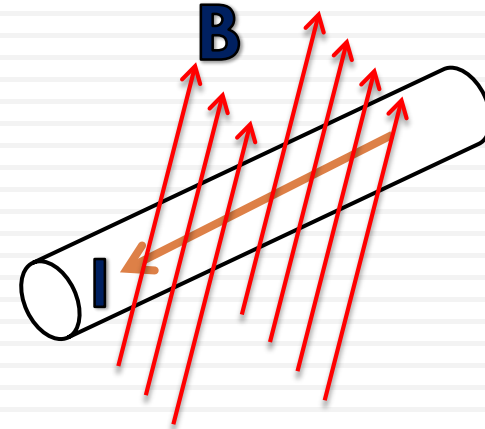
$$e = Blv$$



Introduction: Force & Torque

11

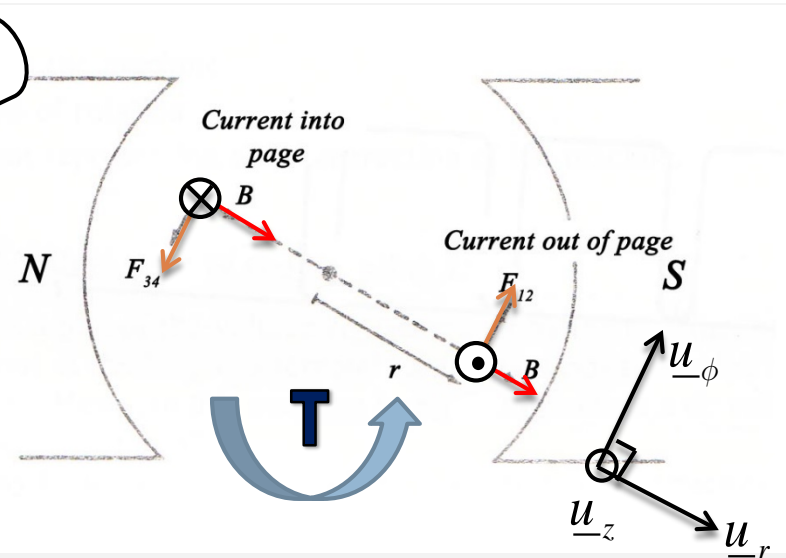
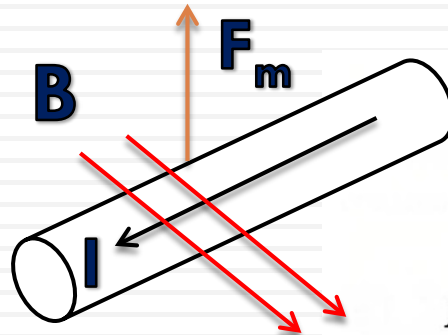
$$\underline{F}_m = I \int \underline{dl} \times \underline{B}$$



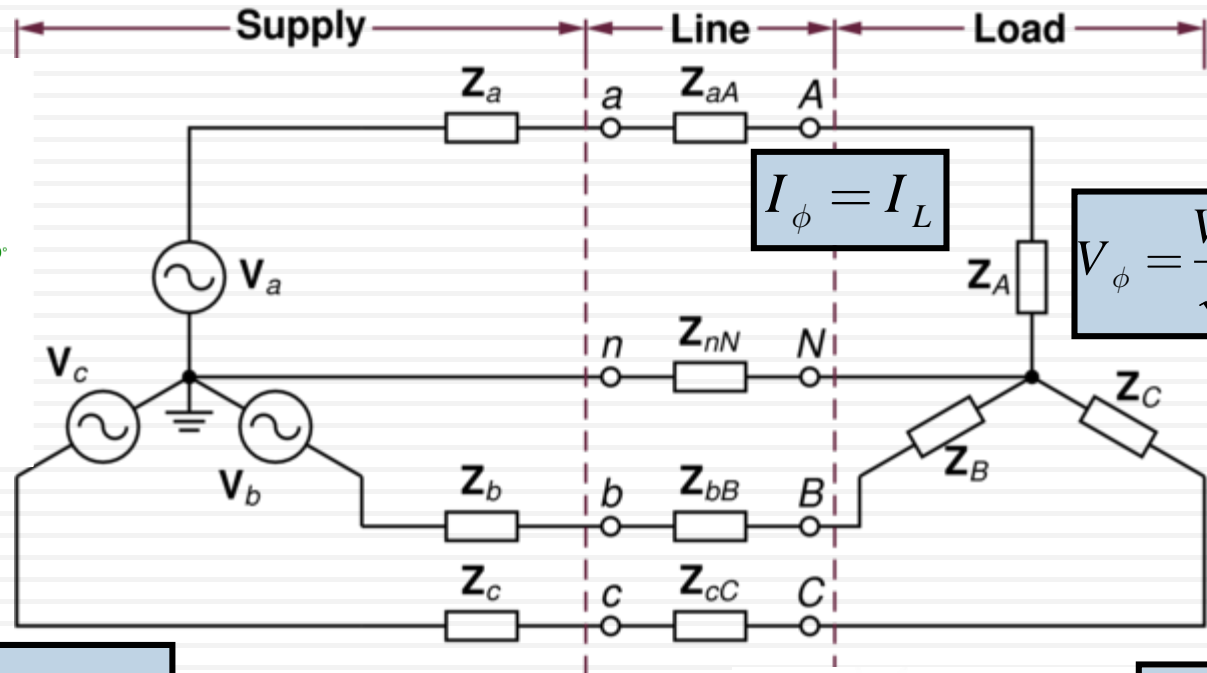
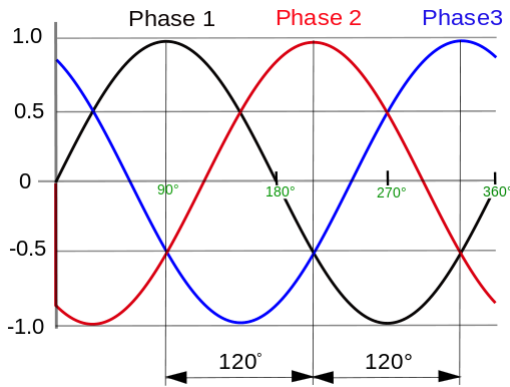
$$F_m = BIL$$

$$T = Fr$$

$$P_m = T \omega$$



Introduction: 3-ph AC Circuits



$$S = 3V_\phi I_\phi$$

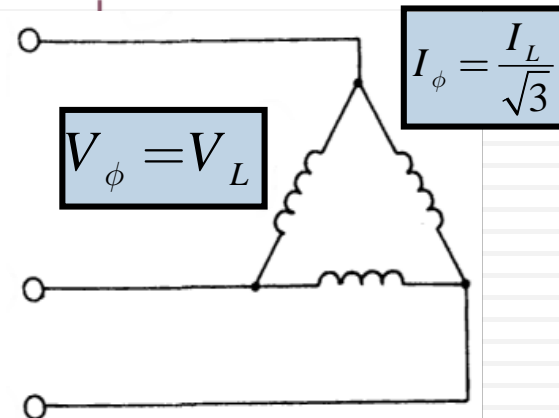
$$S = \sqrt{3}V_L I_L = P + jQ$$

$$P = \sqrt{3}V_L I_L \cos \phi$$

$$P = 3V_\phi I_\phi \cos \phi$$

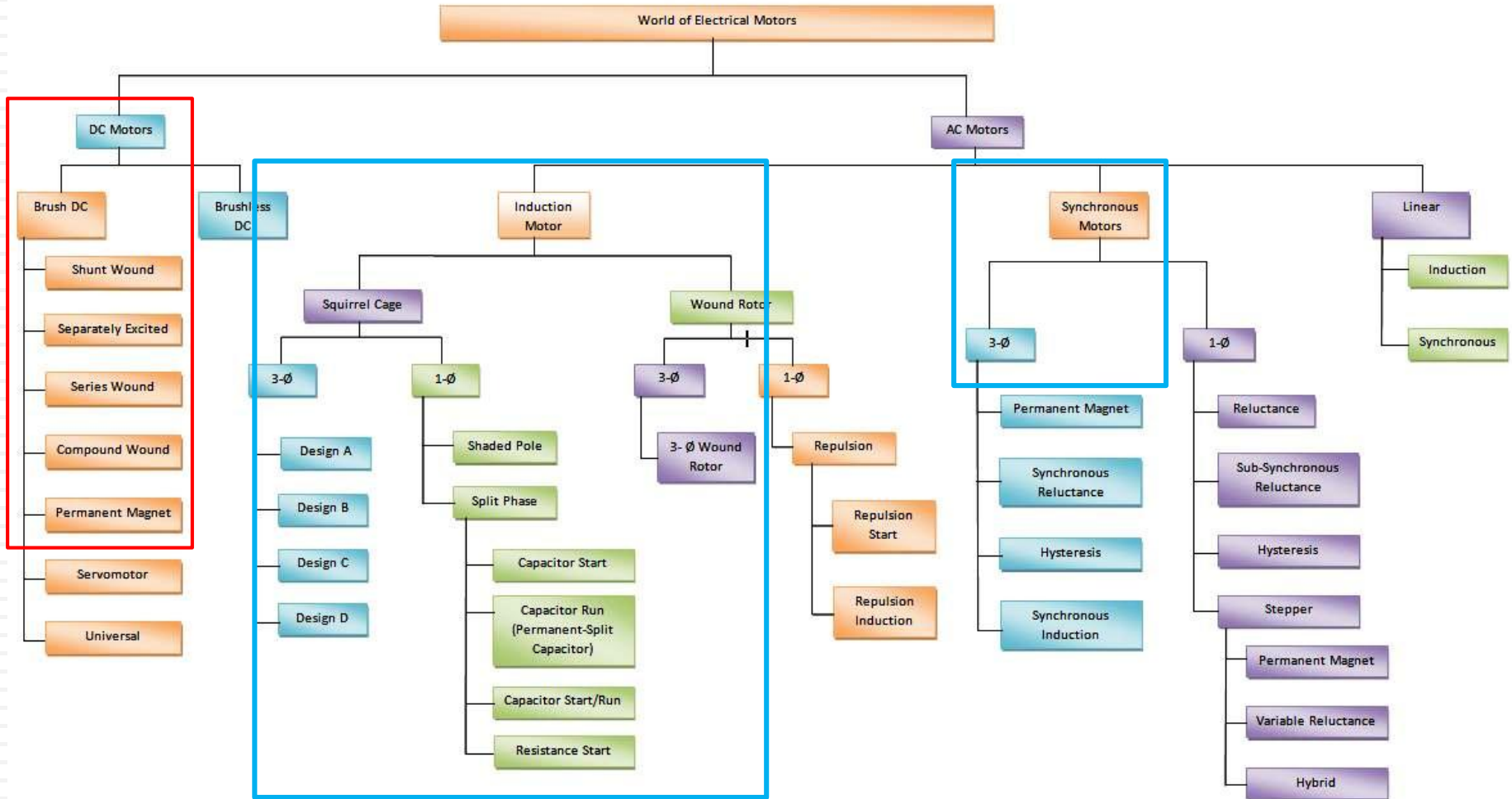
$$Q = \sqrt{3}V_L I_L \sin \phi$$

$$Q = 3V_\phi I_\phi \sin \phi$$



Introduction: Electrical Motors

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Fundamentals of AC Machines

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AC Machines is classified into two main categories:

1. Induction Machines:

- Three-phase induction motor.
- Single-phase induction motors.
- Three-phase induction generator.
- Two-phase induction motor (AC Servo-Motor).
- AC Tacho-generator

Fundamentals of AC Machines

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AC Machines is classified into two main categories:

2. Synchronous Machines:

- Three-phase synchronous generator.
- Three-phase synchronous motor.
- Synchronous reluctance motor.
- Stepper motors.
- Brushless DC motor.

Introduction: Synchronous Generator

Fundamentals of AC Machines

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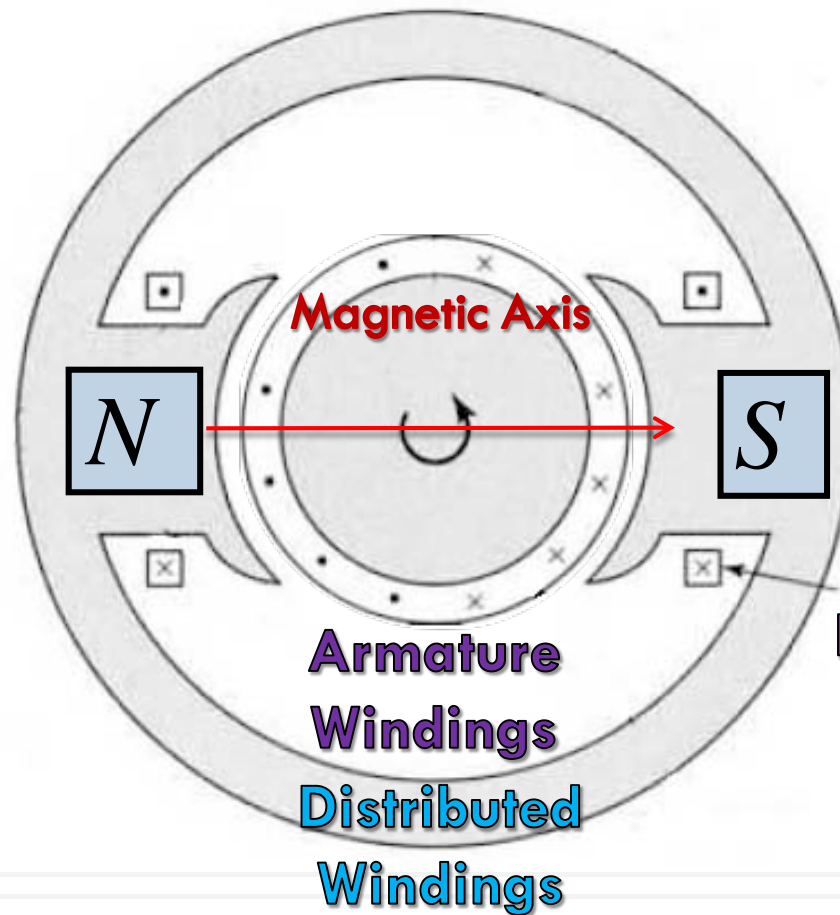
- Magnetic Field Production and Distribution
 - DC Machines
 - Synchronous Machines
 - Induction Machines
- Generated (induced) Voltages
 - Synchronous Machines
 - Induction Machines

Magnetic Field Production & Distribution

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DC Machines

**Two
Magnetic
Poles**



**Salient
Poles**

**Armature
Windings
Distributed
Windings**

**Field Windings
Concentrated
Windings**

Magnetic Field Production & Distribution

20

Synchronous Machines

Salient Poles

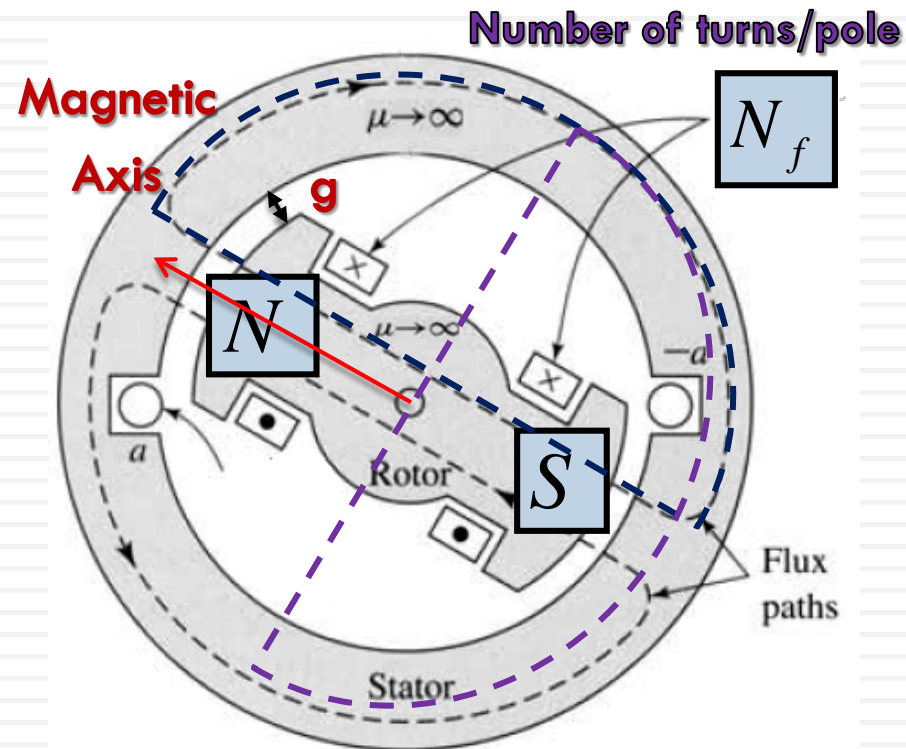
$$\oint_c \underline{H} \cdot \underline{dl} = I_{en}$$

$$\oint_c \underline{H} \cdot \underline{dl} = 2N_f I_f$$

$$H \times g + H \times g \simeq 2N_f I_f$$

Neglecting the reluctance of the steel parts

$$H_g g = N_f I_f = MMF$$



$$M_f = \frac{B_g}{\mu_o} g$$

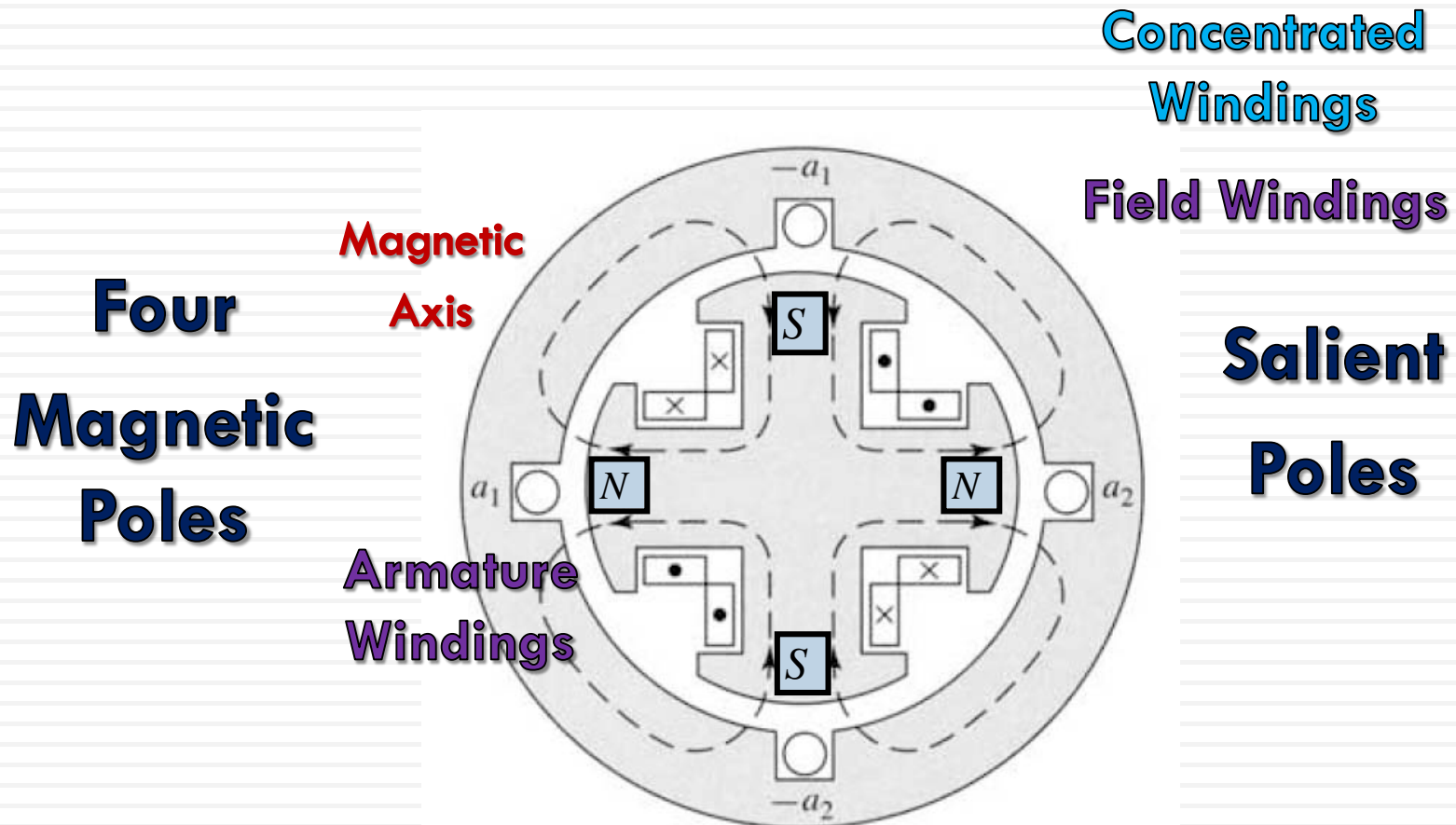
Air Gap
MMF

Magnetic Field Production & Distribution

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Synchronous Machines

Salient Poles

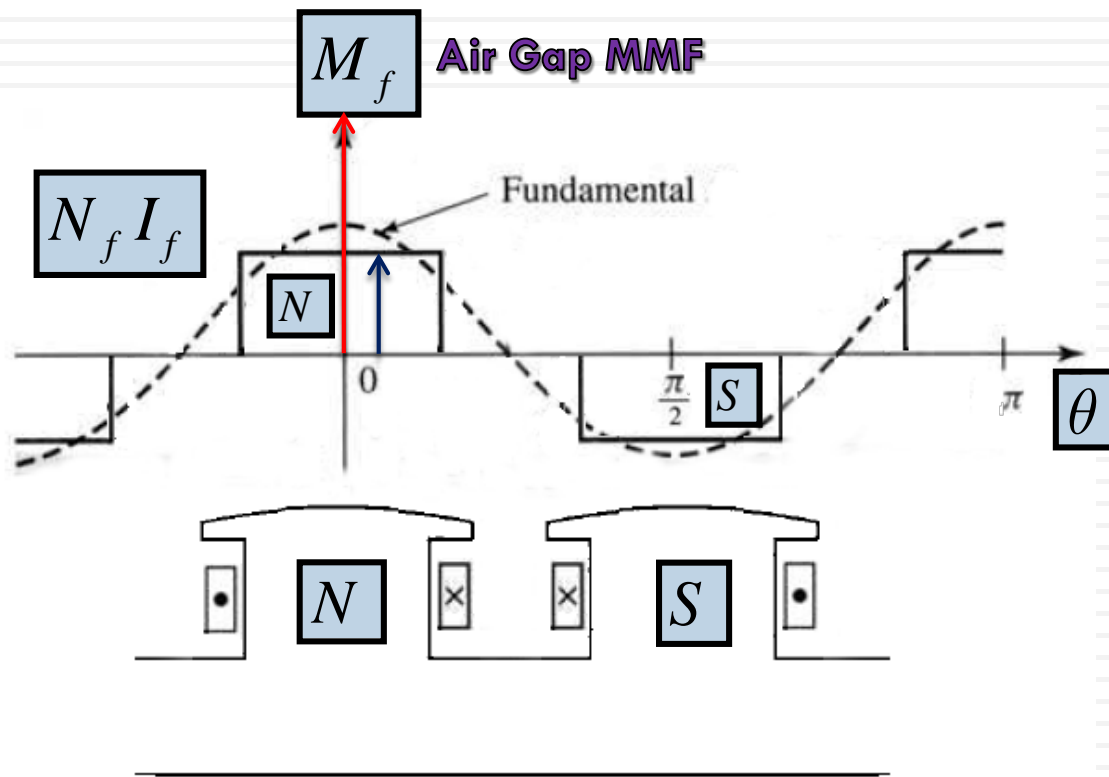


Magnetic Field Production & Distribution

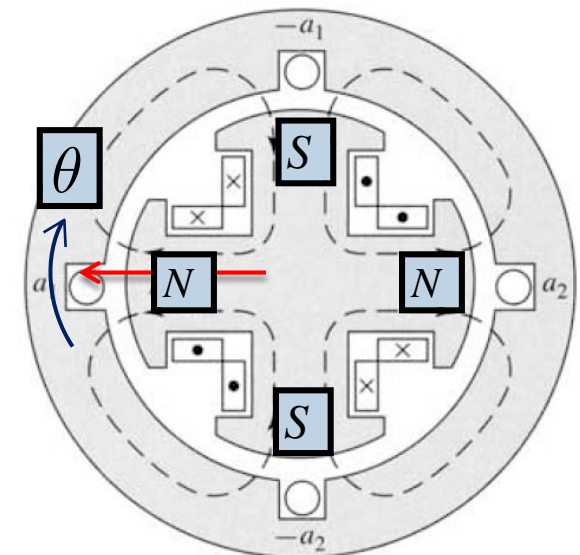
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Synchronous Machines

Salient Poles



MMF Space Distribution



I_f

DC Current

M_f

Stationary Field

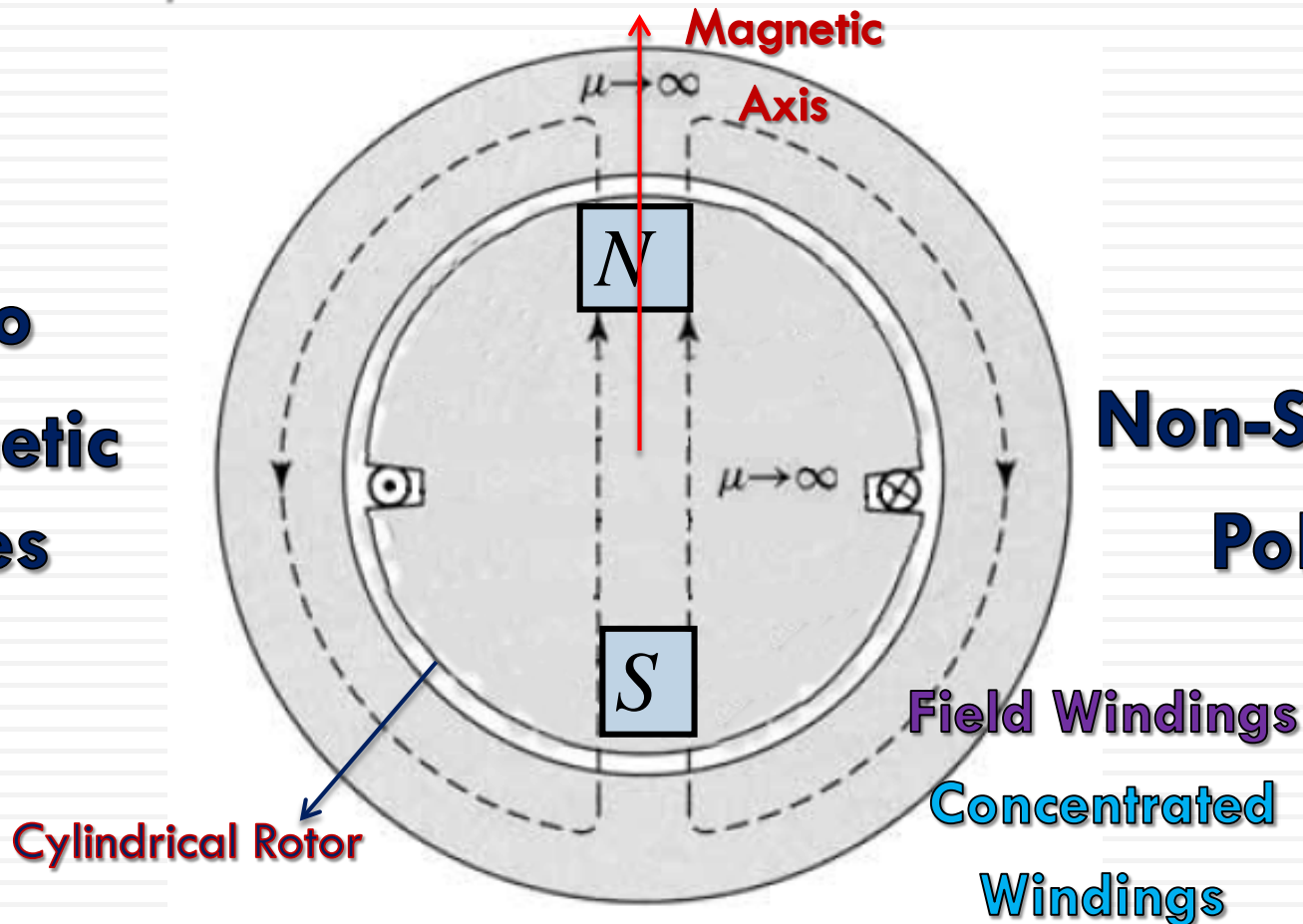
Magnetic Field Production & Distribution

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Synchronous Machines

Non-salient poles

**Two
Magnetic
Poles**



**Non-Salient
Poles**

Magnetic Field Production & Distribution

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Synchronous Machines

Non-salient poles

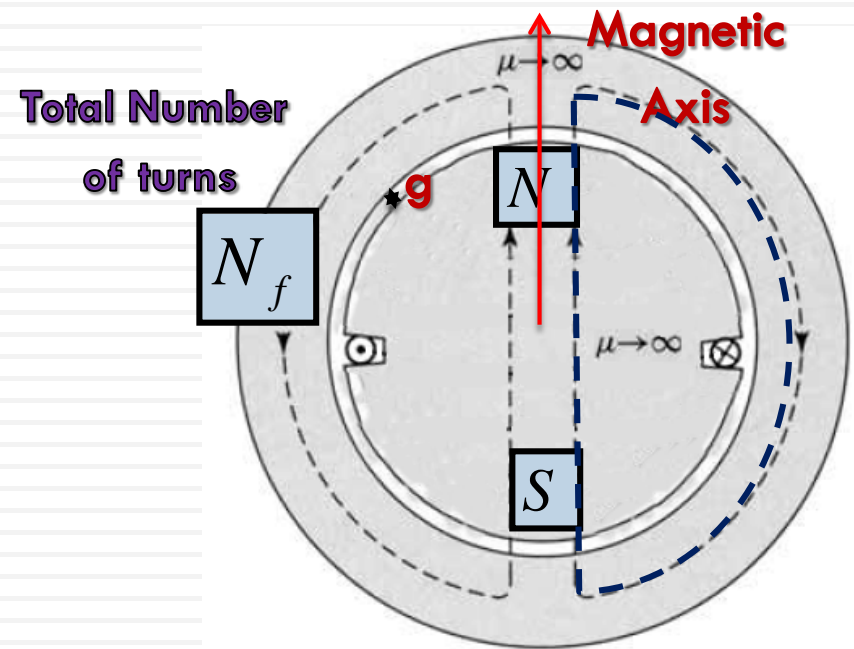
$$\oint_c \underline{H} \cdot \underline{dl} = I_{en}$$

$$\oint_c \underline{H} \cdot \underline{dl} = N_f I_f$$

$$H \times g + H \times g \simeq N_f I_f$$

Neglecting the reluctance of the steel parts

$$H_g g = \frac{N_f I_f}{2} = MMF$$



$$M_f = \frac{B_g}{\mu_o} g$$

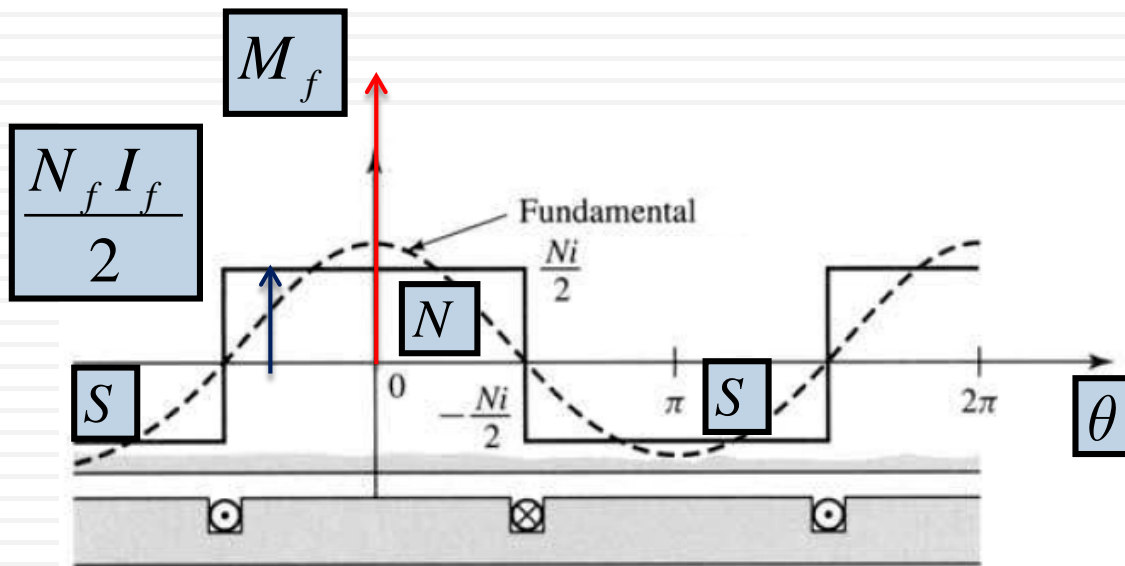
Air Gap MMF

Magnetic Field Production & Distribution

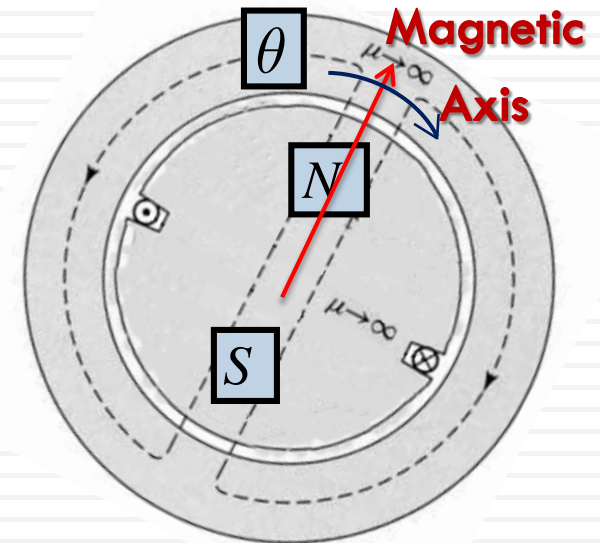
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Synchronous Machines

Non-salient poles



MMF Space Distribution

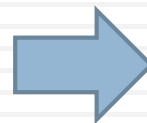


$$\frac{N_f I_f}{2p} \quad \text{For any number of poles } (2p)$$

Remember:

$$f(\theta) = \frac{4}{\pi} \sum_{n=1,3,5,\dots} \frac{F}{n} \cos(n\theta)$$

Fourier Series for a square wave



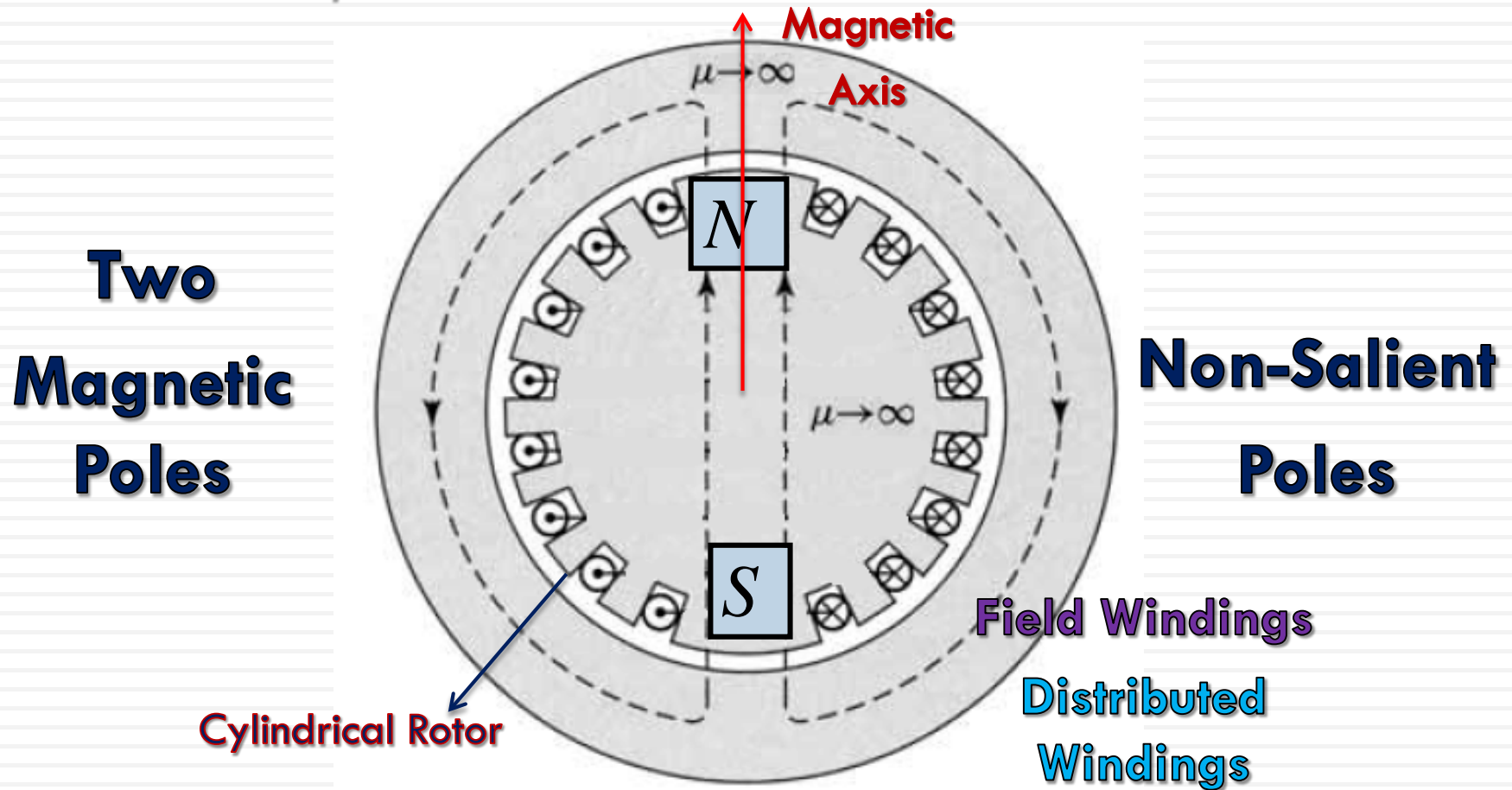
$$M(\theta) = \frac{4}{\pi} \frac{N_f I_f}{2p} \sum_{h=1,3,5,\dots} \frac{1}{h} \cos(h\theta)$$

Magnetic Field Production & Distribution

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Synchronous Machines

Non-salient poles



Magnetic Field Production & Distribution

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Synchronous Machines

Non-salient poles

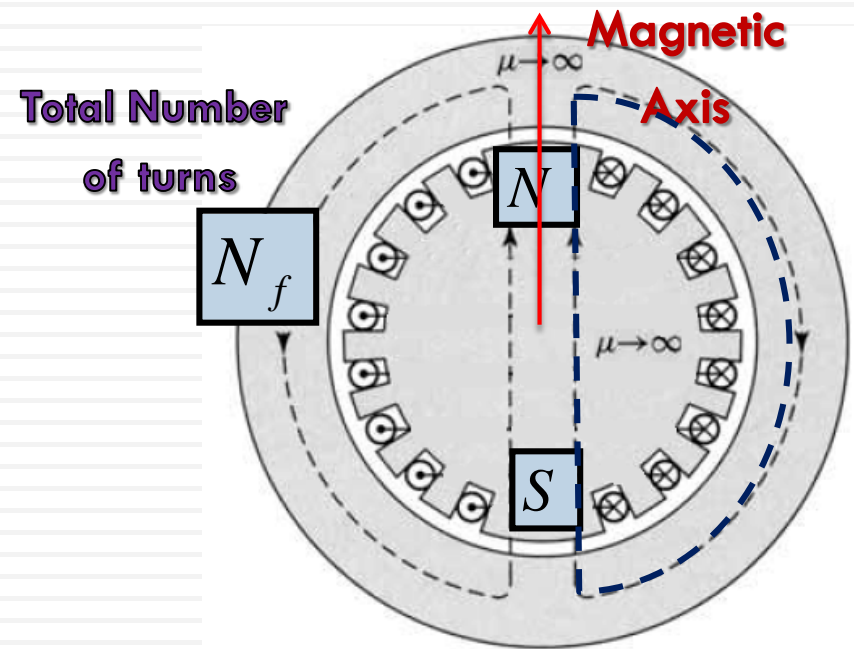
$$\oint_c \underline{H} \cdot \underline{dl} = I_{en}$$

$$\oint_c \underline{H} \cdot \underline{dl} = N_f I_f$$

$$H \times g + H \times g \simeq N_f I_f$$

Neglecting the reluctance of the steel parts

$$H_g g = \frac{N_f I_f}{2} = MMF$$



$$M_f = \frac{B_g}{\mu_o} g$$

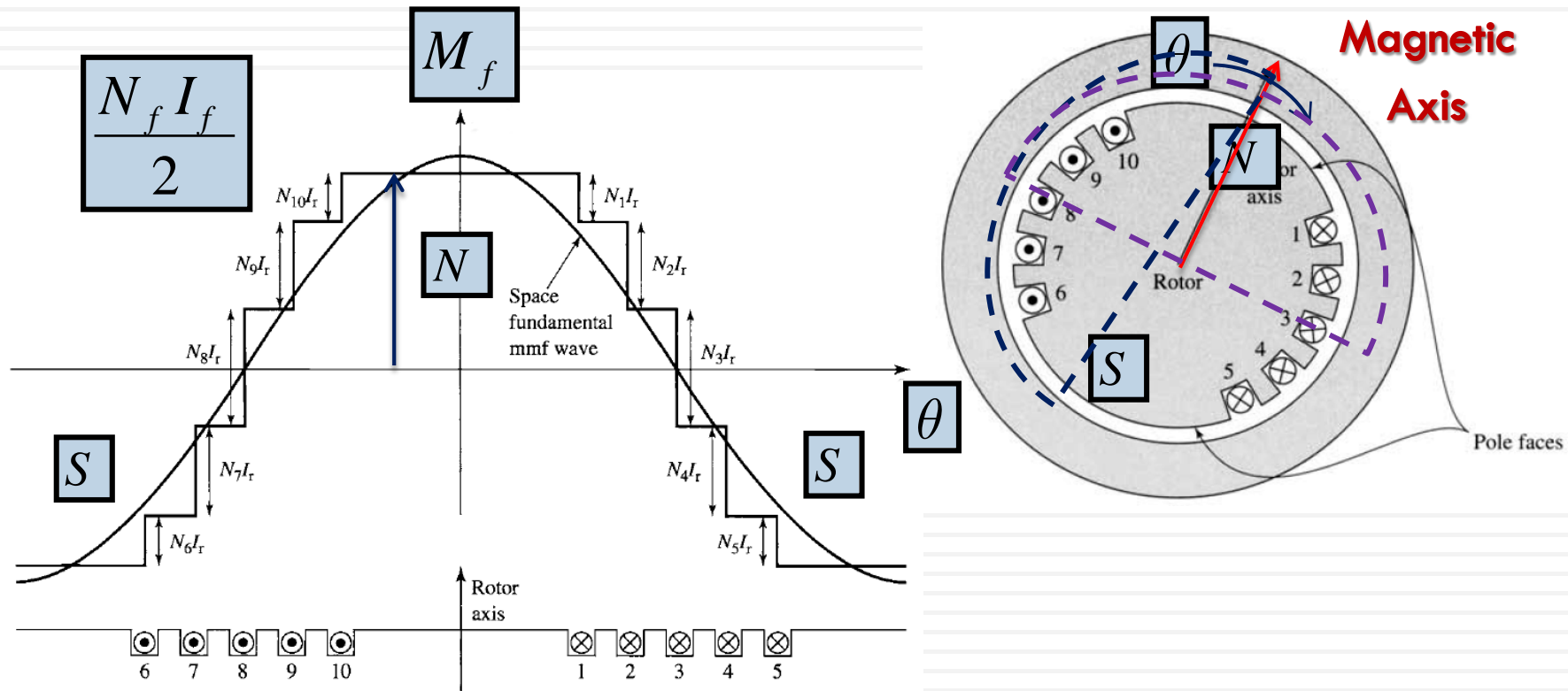
Air Gap MMF

Magnetic Field Production & Distribution

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Synchronous Machines

Non-salient poles



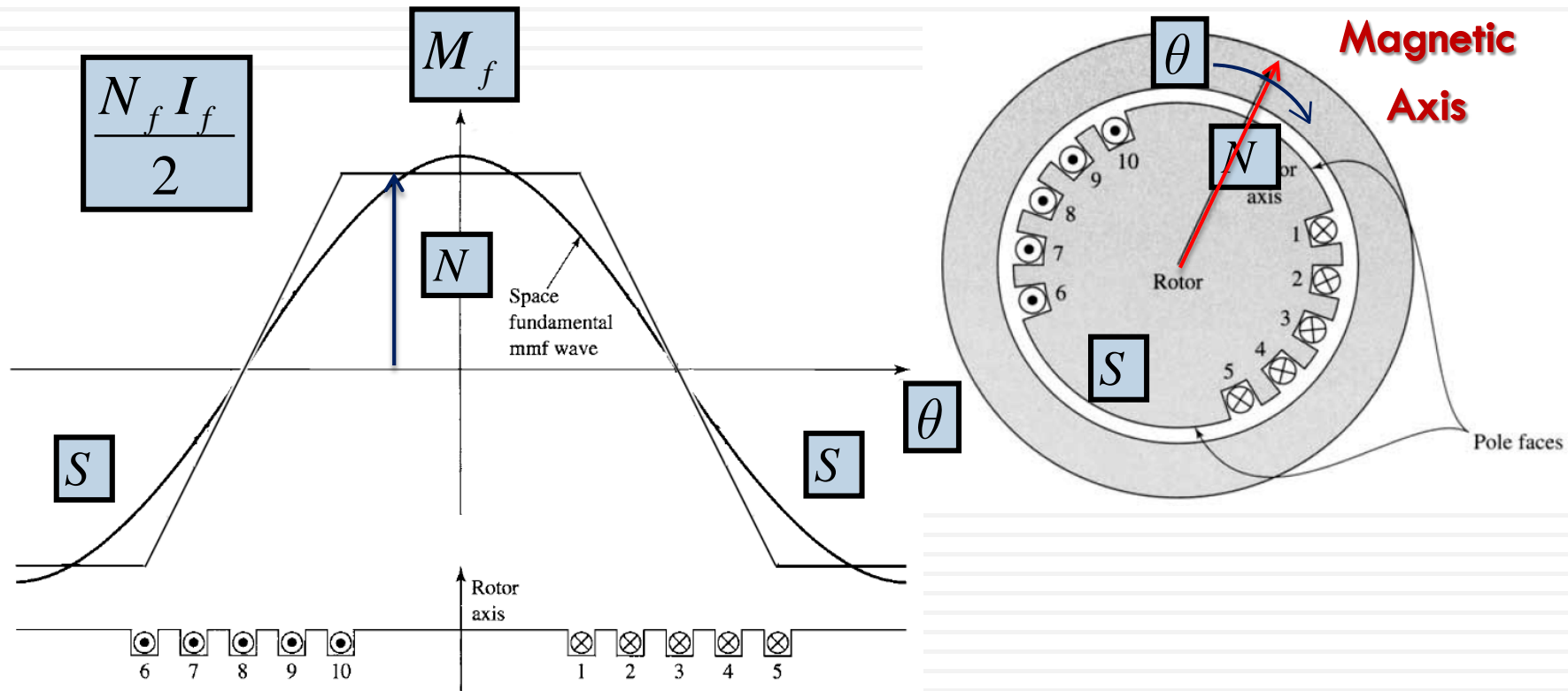
MMF Space Distribution

Magnetic Field Production & Distribution

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Synchronous Machines

Non-salient poles



MMF Space Distribution

Magnetic Field Production & Distribution

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Synchronous Machines

Non-salient poles

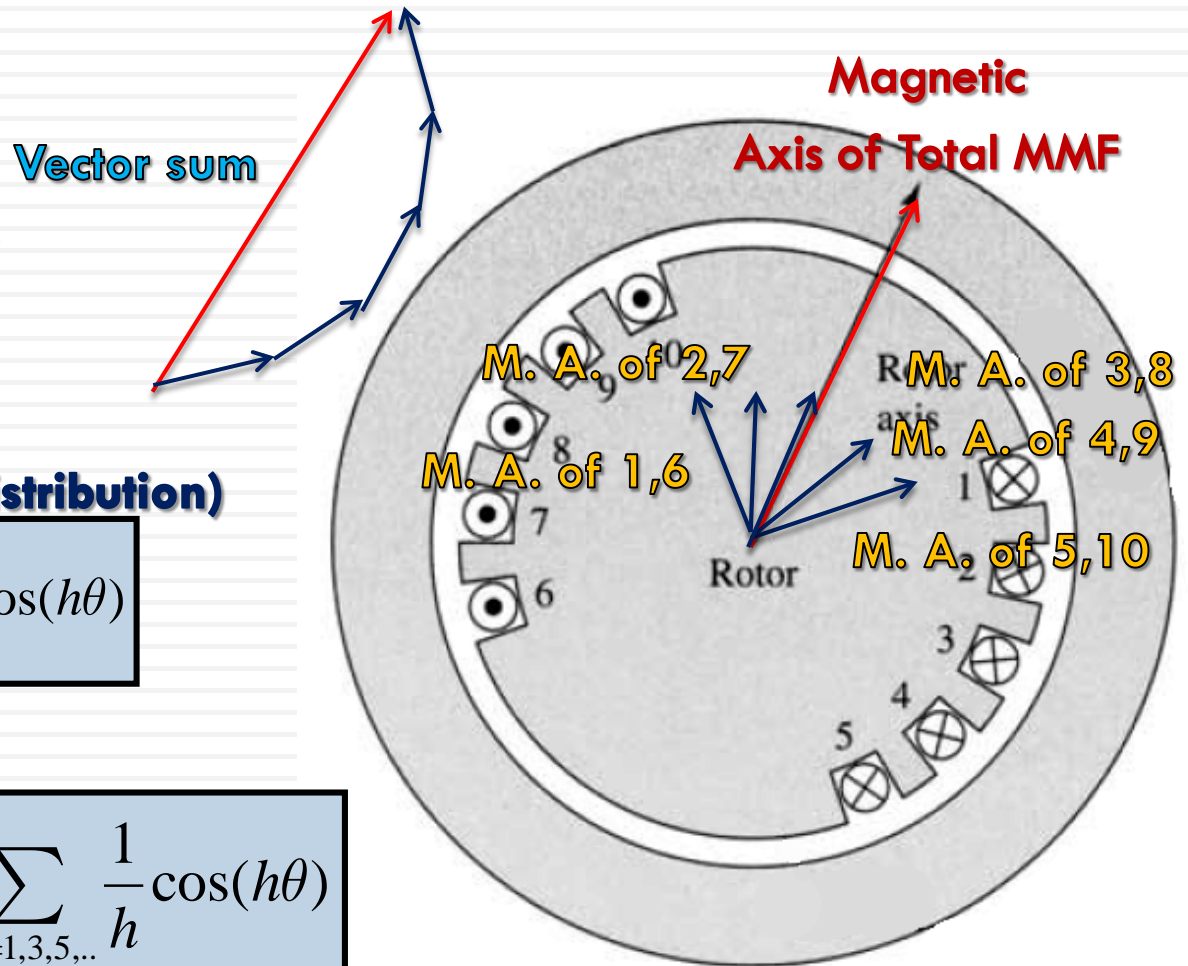
Distribution (Pitch) Factor

$$k_d = \frac{\text{vector sum}}{\text{arithmetic sum}}$$

Arithmetic Sum (i.e. no distribution)

$$M(\theta) = \frac{4 N_f I_f}{\pi 2p} \sum_{h=1,3,5,\dots} \frac{1}{h} \cos(h\theta)$$

$$M(\theta) = \frac{4 N_f I_f}{\pi 2p} k_d \sum_{n=1,3,5,\dots} \frac{1}{h} \cos(h\theta)$$



Magnetic Field Production & Distribution

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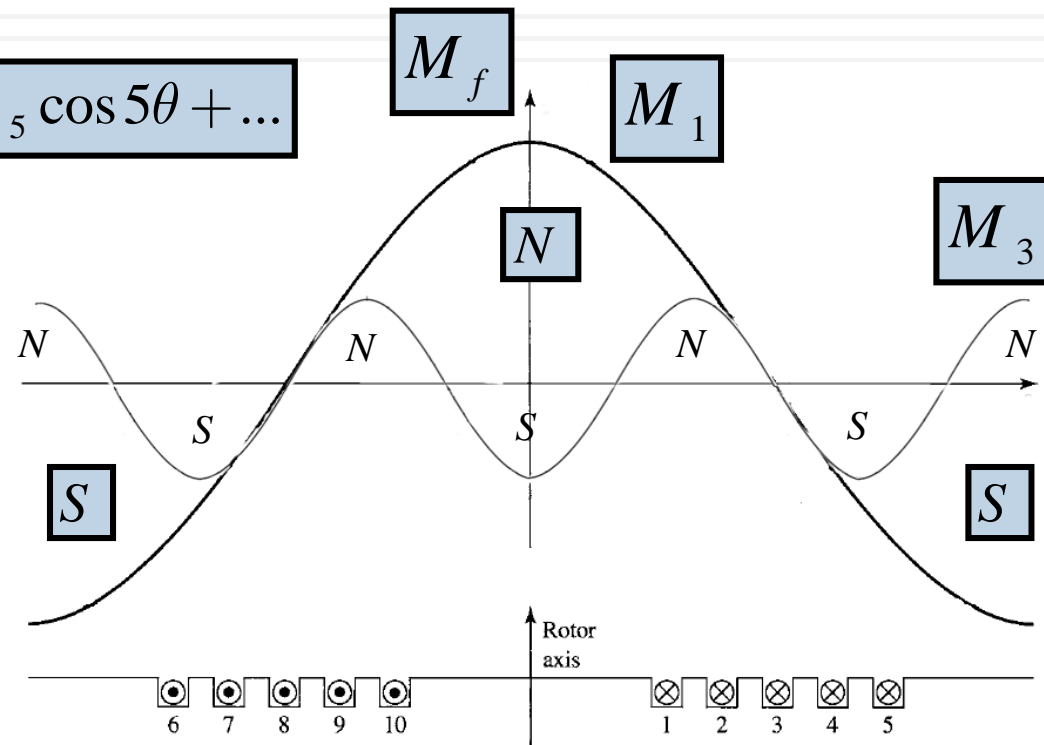
Synchronous Machines

Space Harmonics

$$M_f = M_1 \cos \theta + M_3 \cos 3\theta + M_5 \cos 5\theta + \dots$$

$$M_f = \frac{B_g}{\mu_o} g$$

$$B_g = \frac{M_f}{g} \mu_o$$



$$B_g = B_1 \cos \theta + B_3 \cos 3\theta + B_5 \cos 5\theta + \dots$$

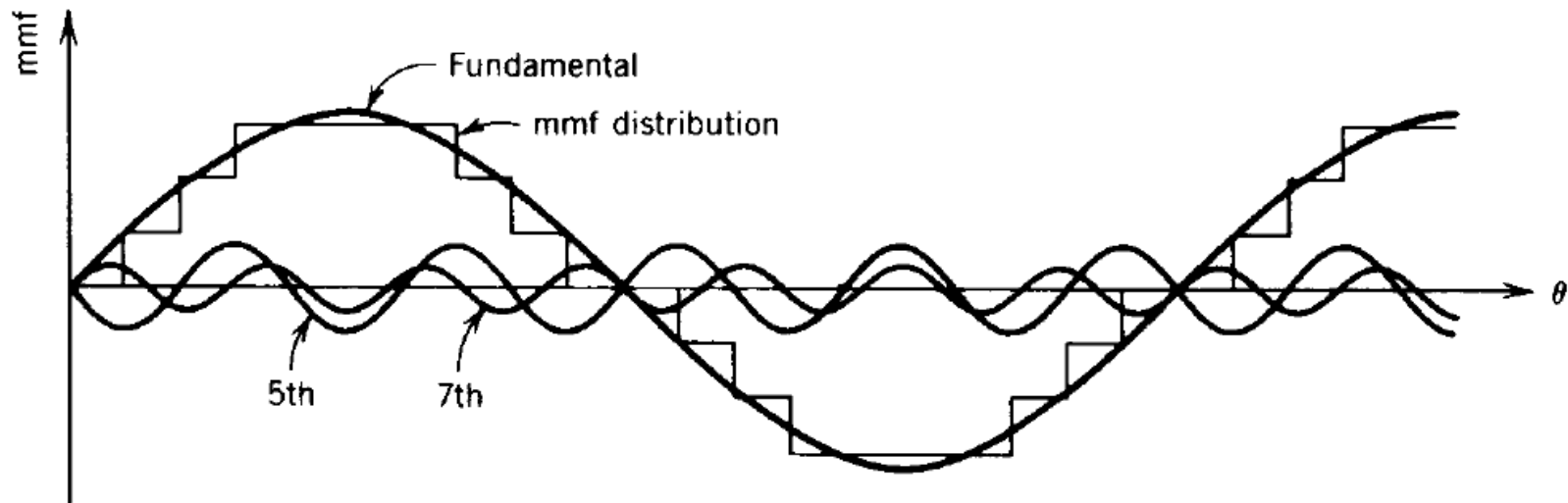
Magnetic Field Production & Distribution

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Synchronous Machines

Space Harmonics

$$M_f = M_1 \cos \theta + M_3 \cos 3\theta + M_5 \cos 5\theta + \dots$$



$$B_g = B_1 \cos \theta + B_3 \cos 3\theta + B_5 \cos 5\theta + \dots$$