Power Electronics

Introduction to Motor Drives

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Outlines

12.1 Introduction

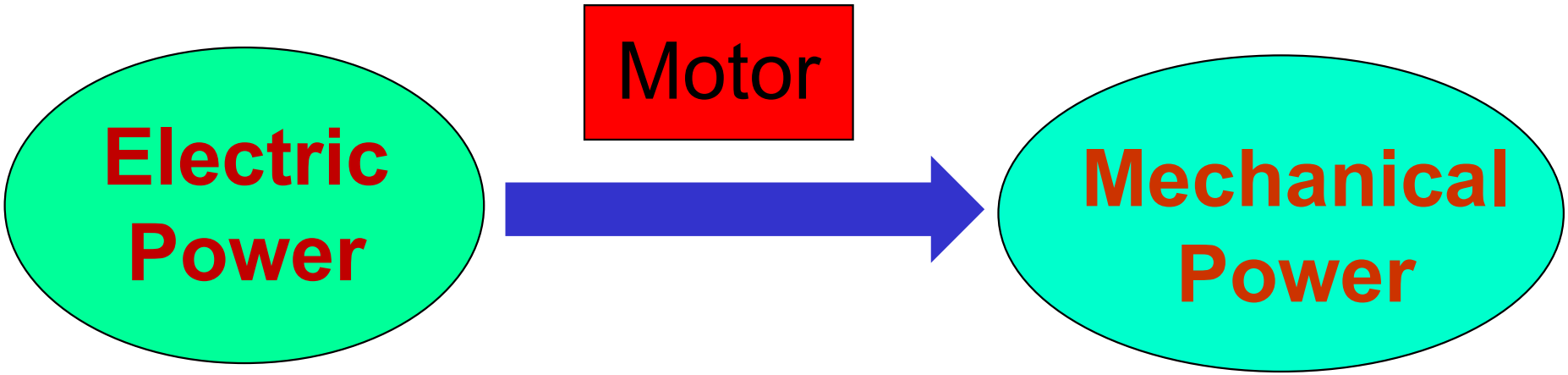
Why should we study motor drives?

12.2 Criteria for Selecting Drive Components

Introduction

MOTOR DRIVES *deal with*

the energy conversion from electric power to mechanical power



Introduction

Why should we study

Motor Drives?

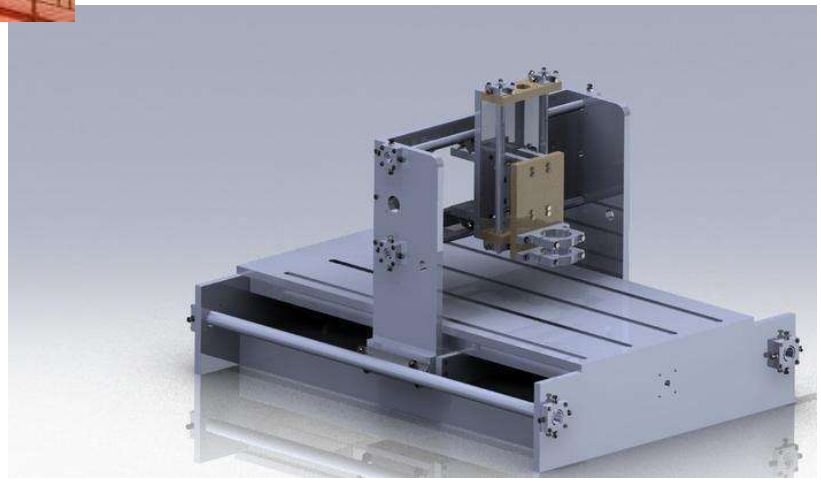
Introduction

Industrial Applications

Rolling mill

Robot

Water pump



CNC machine tools

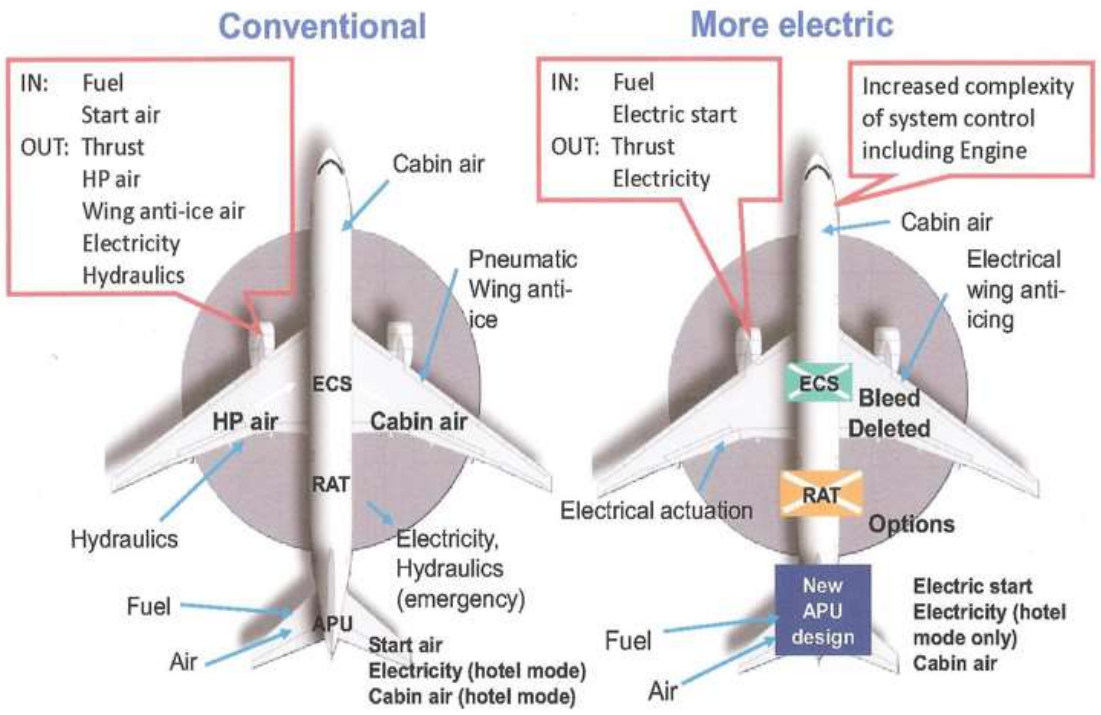
Chap.12 Introduction to Motor Drives

Introduction

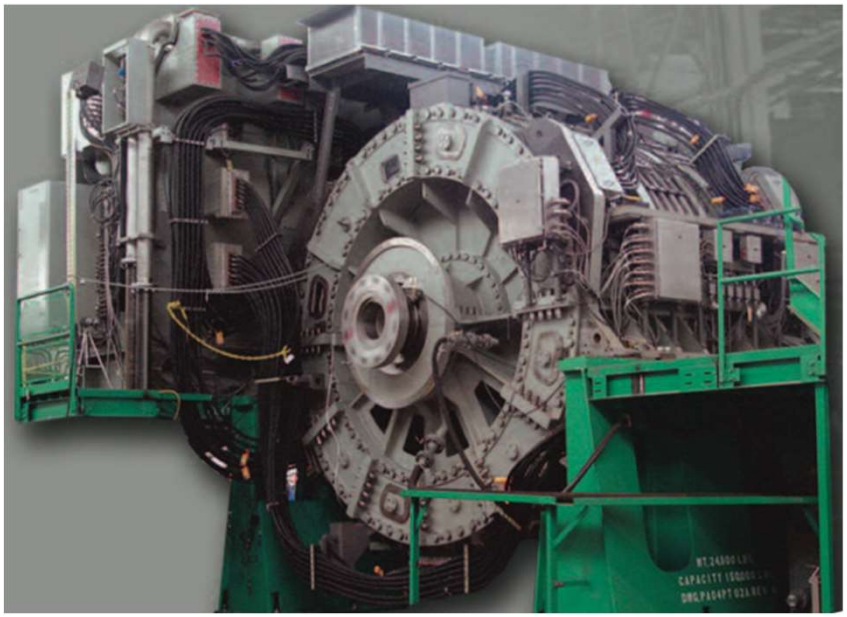
Applications in Transportations

Introduction

Applications in Transportations



Comparison between conventional aircraft and more electric aircraft



Direct-drive permanent magnet propulsion motor for shipboard

Introduction

Applications for Consumers

PC

Washing Machine

Air-condition

Introduction

Why should we study Motor Drives?

- Motor drives are **widely used** in many industrial applications and also home appliances.

- Motor drives are used in a very **wide power range**, from a few watts to many thousands of kilowatts.

Introduction

Why need we learn Motor Drives in Power Electronics?

Introduction

General description of motor drive system

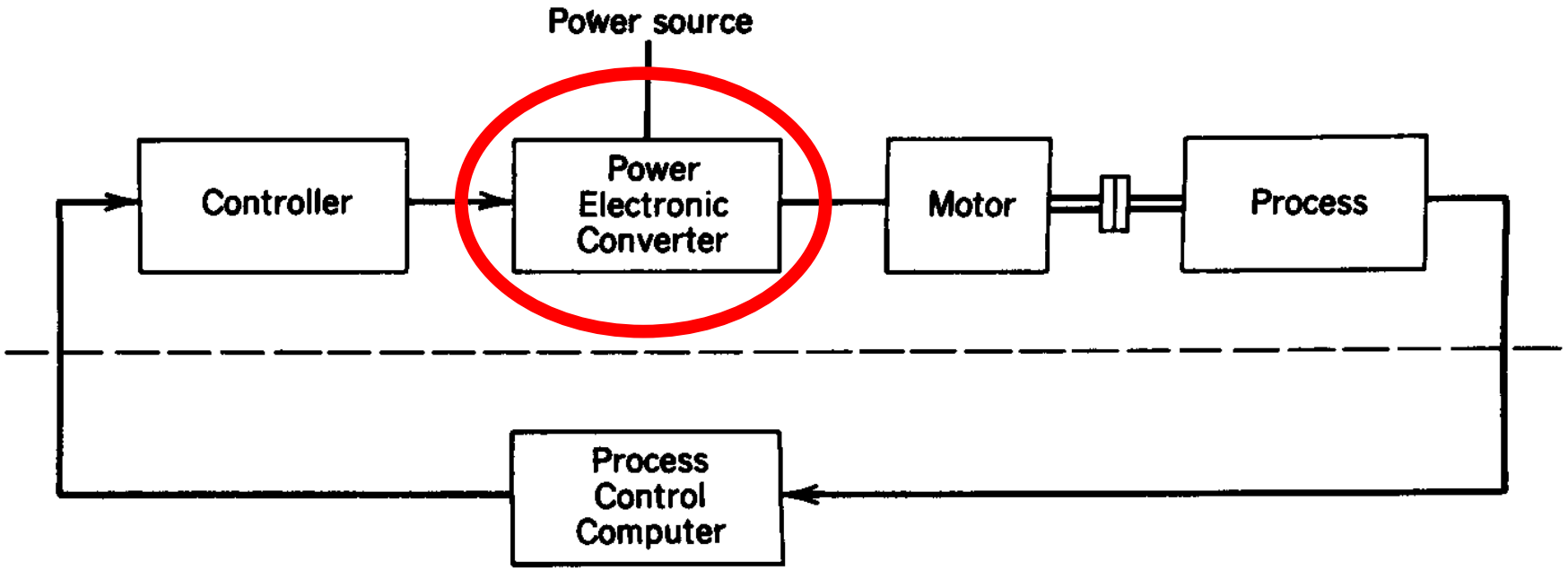


Figure 12-1 Control of motor drives.

• In all drives where the speed and position are controlled, a power electronic converter is needed as an interface between the input power and the motor.

Introduction

Why need we learn Motor Drives in Power Electronics?

- Control of motor drives is realized through power electronics converters, which are the key elements in drive systems.

Introduction

Motor Drive Types

- dc motor drives
- induction motor drives
- synchronous motor drives

} ac motor drives

Introduction

- The basic control targets of motor drives are the speed and position.

Example —— Servo drive

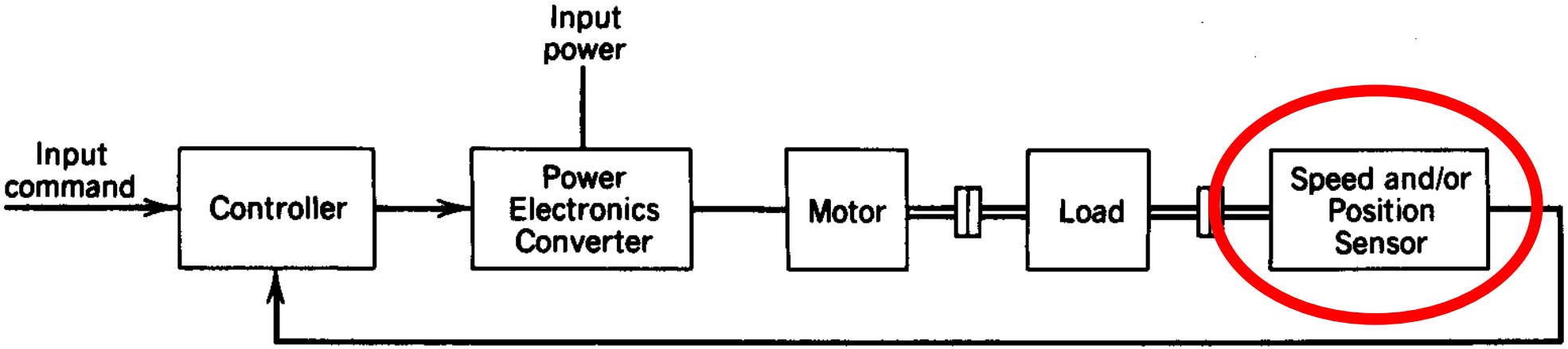


Figure 12-2 Servo drives.

- In servo drives, the response time and the accuracy with which the motor follows the speed and position commands are extremely important.

Introduction

- However, in a large number of applications, the accuracy and the response time of the motor to follow the speed command is not critical.

Example —— Adjustable-speed drive in air-condition

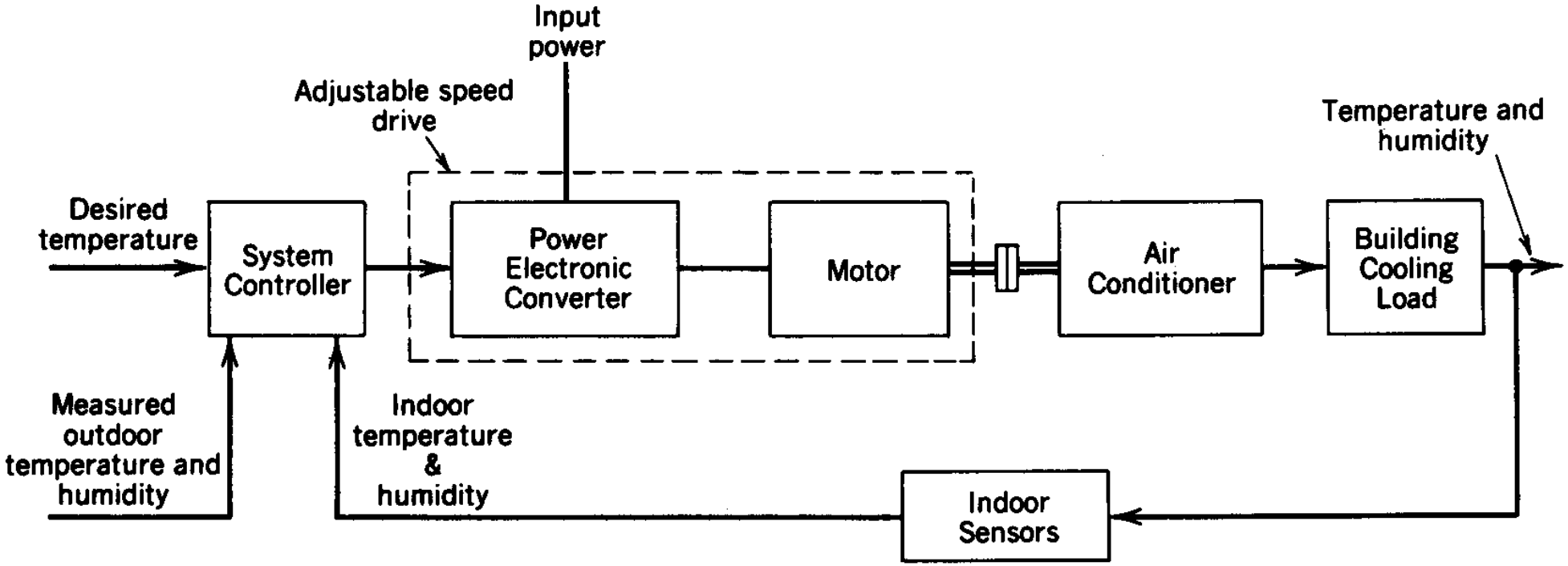


Figure 12-3 Adjustable-speed drive in an air conditioning system.

Criteria for Selecting Drive Components

- Match between the motor and the load
- Thermal considerations in selecting the motor
- Match between the motor and the power electronic converter
- Servo drive control and current limiting
- Current limiting in adjustable-speed drives

Criteria for Selecting Drive Components

12.2.1 Match between the motor and the load

$$T - T_{\text{load}} = J\frac{d\omega}{dt}$$

- Prior to selecting the drive components, the load parameter and requirements such as the load inertia, maximum speed, speed range and direction of motion must be available.

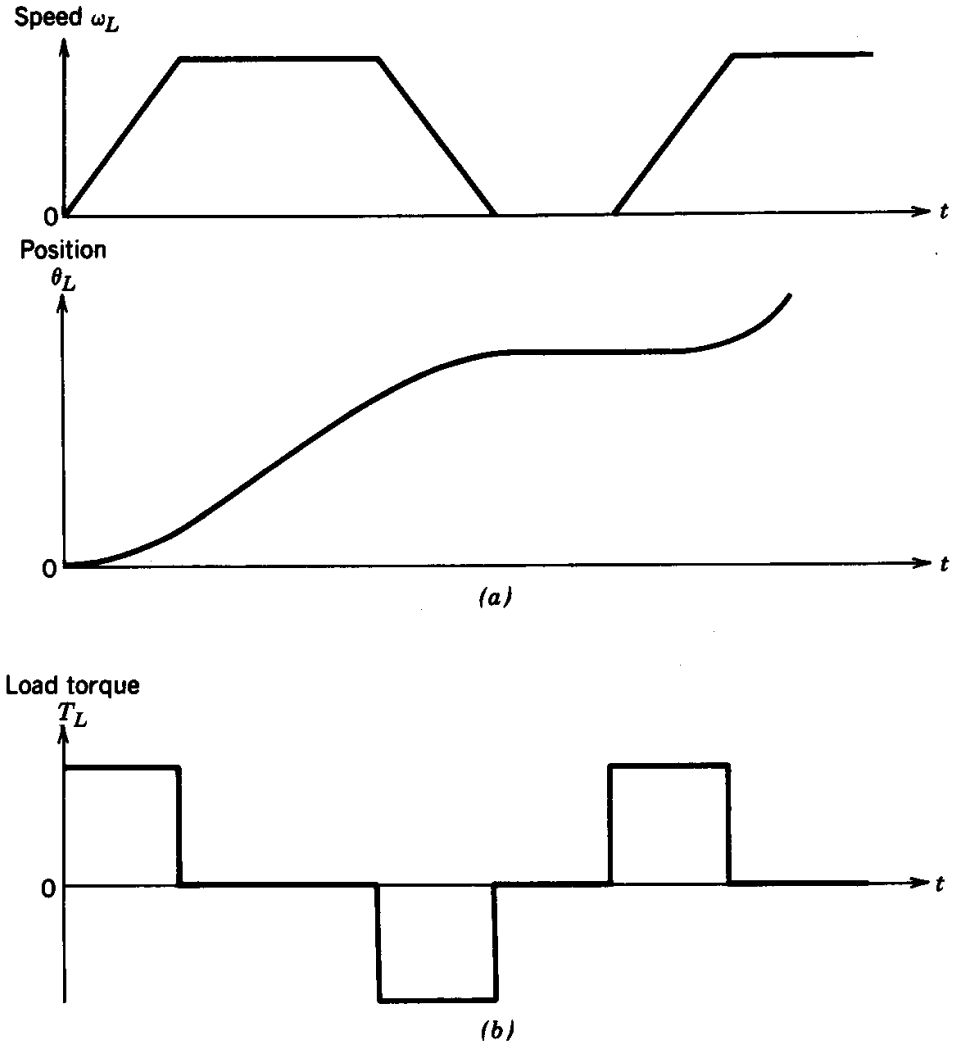


Figure 12-4 Load profile: (a) load motion profile; (b) load–torque profile (assuming a purely inertial load).

Criteria for Selecting Drive Components

12.2.1 Match between the motor and the load

$$T - T_{\text{load}} = J\frac{d\omega}{dt}$$

- As shown in the figure, the torque required by the load peaks during the acceleration and deceleration (assuming a purely inertial load).

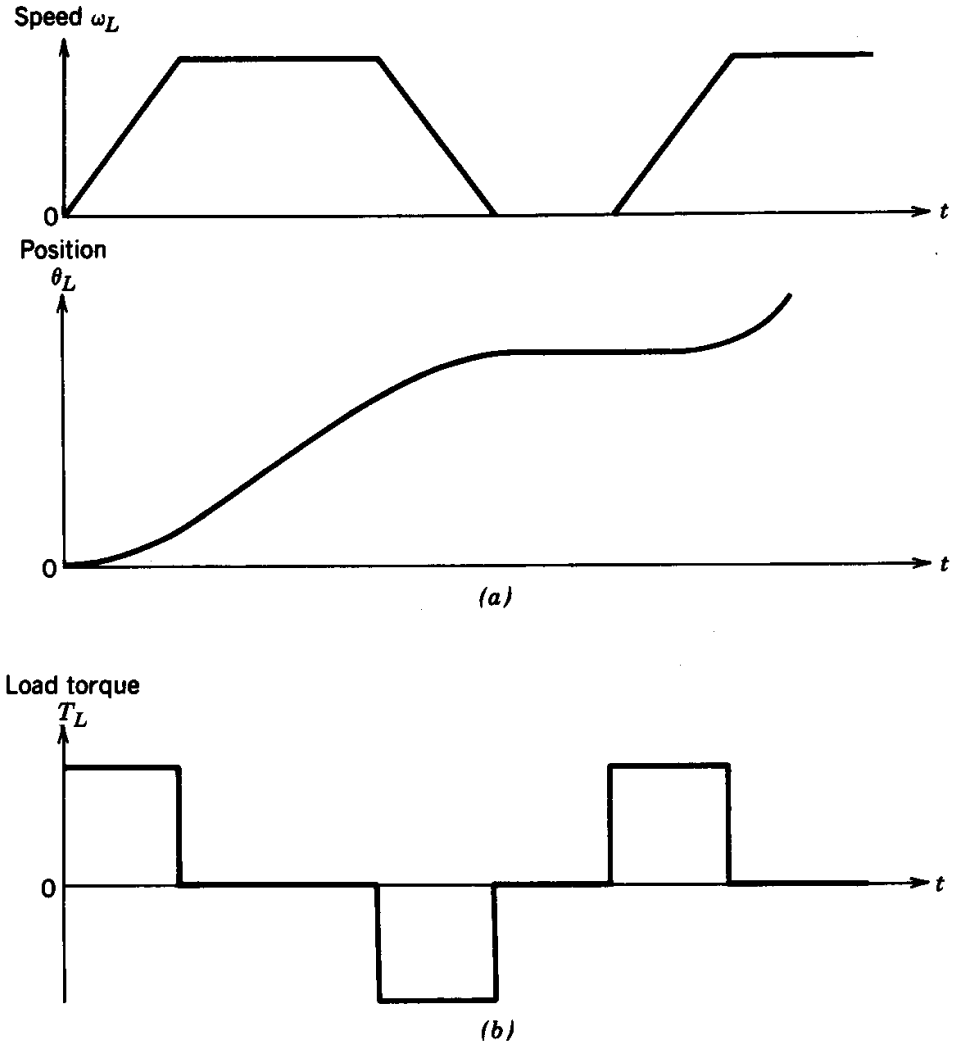
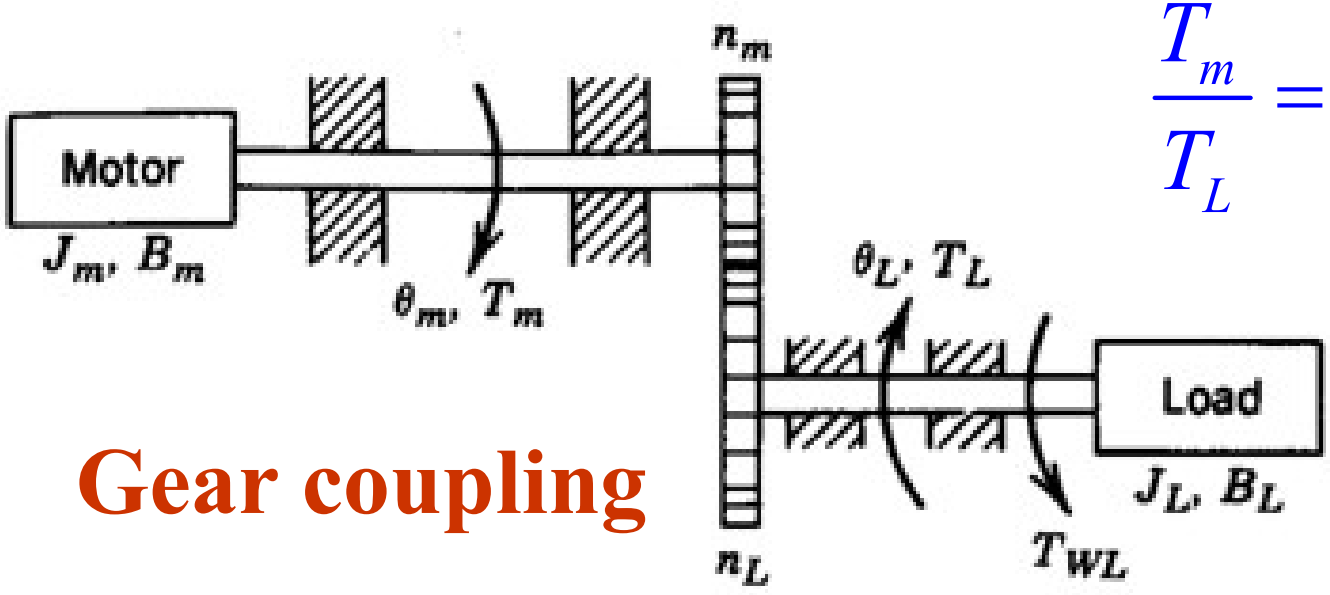


Figure 12-4 Load profile: (*a*) load–motion profile; (*b*) load–torque profile (assuming a purely inertial load).

Criteria for Selecting Drive Components

12.2.1 Match between the motor and the load

- In order to drive a rotating load, the motor and the load must be coupled directly or by some devices, such as gear, feed-screw（丝杠） and belt-pulley（皮带轮）.



Gear coupling

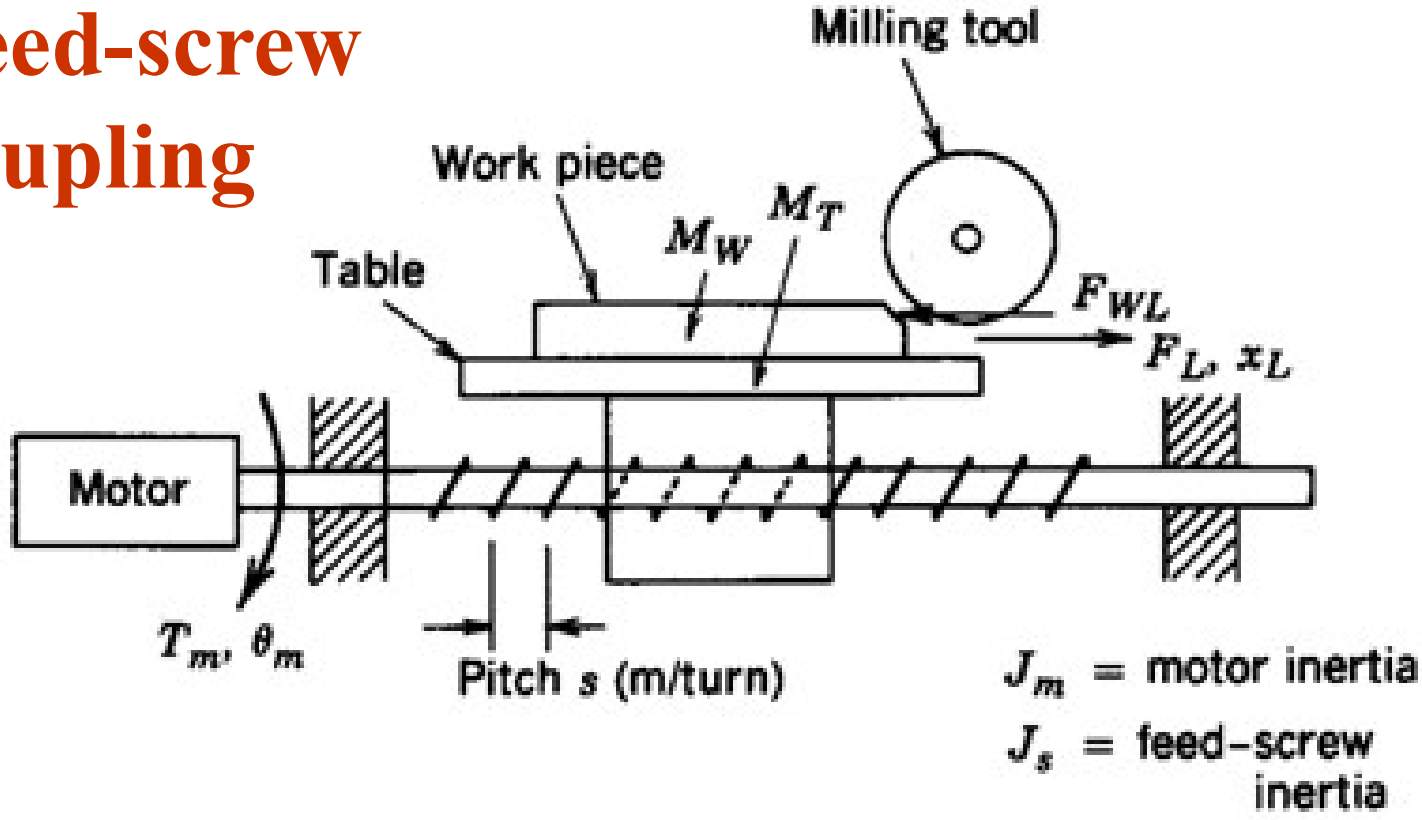
$$\frac{T_m}{T_L} = \frac{\omega_L}{\omega_m} = \frac{\theta_L}{\theta_m} = \frac{n_m}{n_L} = a$$

n_m and n_L are the numbers of teeth.

Criteria for Selecting Drive Components

12.2.1 Match between the motor and the load

Feed-screw coupling



$$\frac{T_m}{F_L} = \frac{v_L}{\omega_m} = \frac{x_L}{\theta_m} = \frac{s}{2\pi} = a$$

s is the pitch of the feed screw.

Criteria for Selecting Drive Components

12.2.2 Thermal considerations in selecting the motor

- In electric machine, the electromagnetic torque is proportional to the motor current, provided the flux in the air gap of the motor is kept constant.

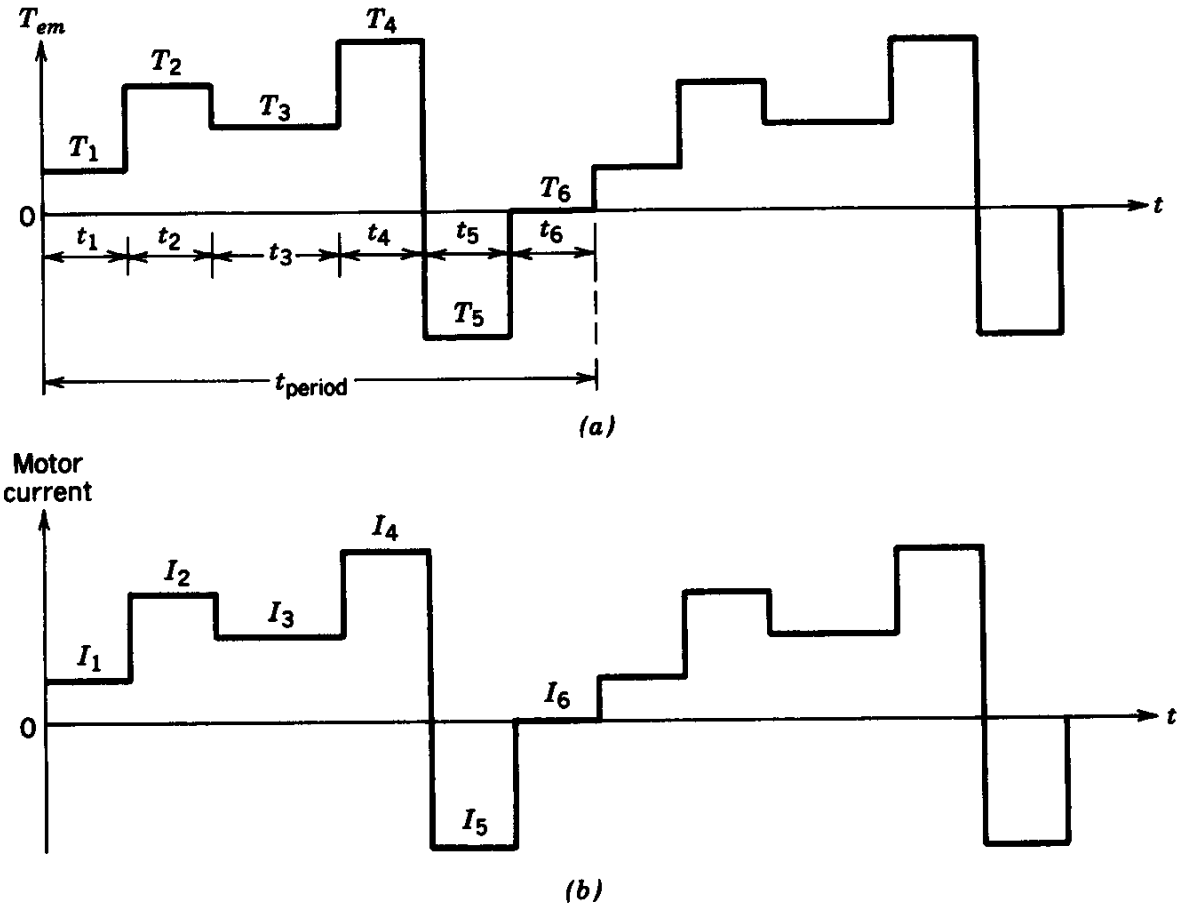


Figure 12-6 Motor torque and current.

Criteria for Selecting Drive Components

12.2.2 Thermal considerations in selecting the motor

- The power loss P_R in the winding resistance R_M due to the motor current is a large part of the total motor losses, which get into heat.

$$P_R = R_M I_{\text{rms}}^2$$

$$I_{\text{rms}}^2 = \frac{\sum_{k=1}^{m} I_k^2 t_k}{t_{\text{period}}}$$

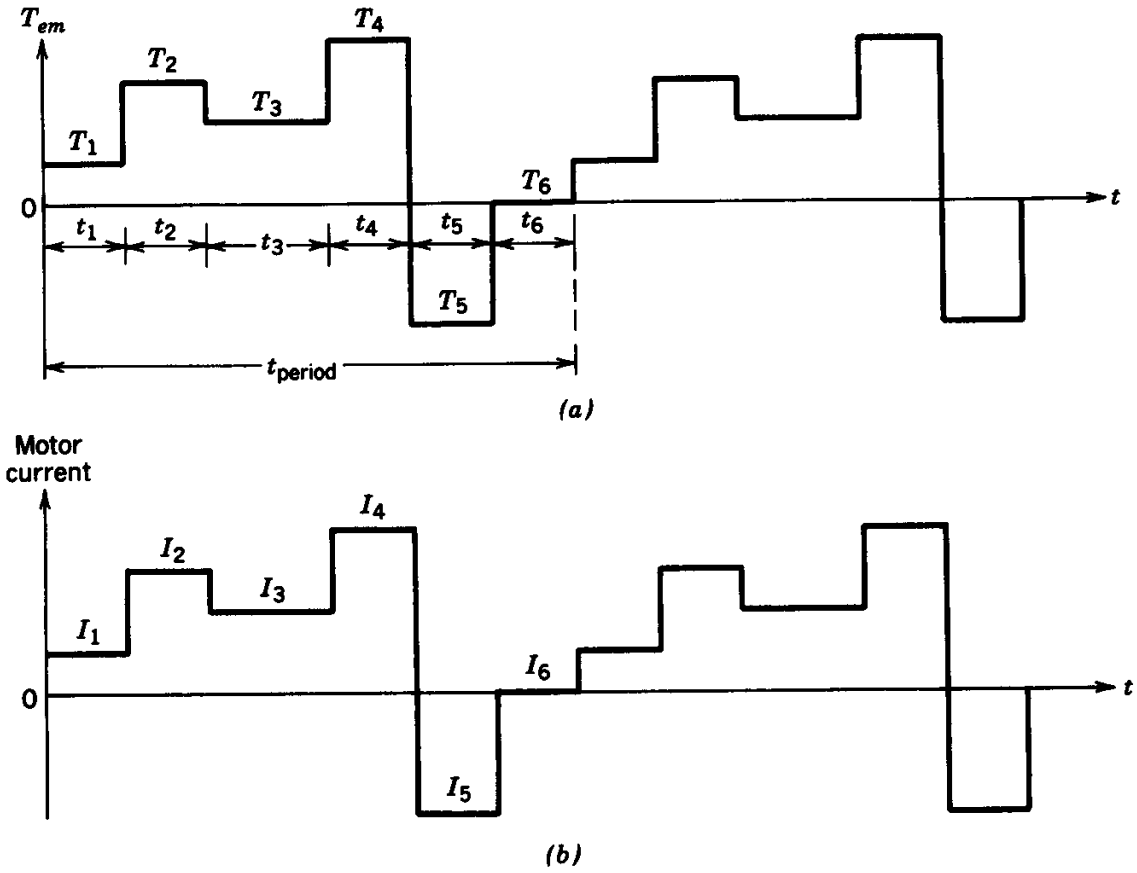


Figure 12-6 Motor torque and current.

Criteria for Selecting Drive Components

12.2.2 Thermal considerations in selecting the motor

• Because of the motor current being linearly proportional to the motor torque, the rms value of the motor torque is,

$$T_{\text{em,rms}}^2 = k_1 I_{\text{rms}}^2 \qquad T_{\text{em,rms}}^2 = k_1 \frac{\sum_{k=1}^{m} I_k^2 t_k}{t_{\text{period}}} \qquad P_R = k_2 T_{\text{em,rms}}^2$$

• There are 5 kinds of losses within the motor that contribute to its heating,

$$P_{\text{loss}} = P_R + P_{\text{FW}} + P_{\text{EH}} + P_s + P_{\text{stray}}$$

Friction & windage

Eddy current & hysteresis

Motor current ripple

Stray loss

Criteria for Selecting Drive Components

12.2.2 Thermal considerations in selecting the motor

- In steady-state condition, the motor temperature rise is,

$$\Delta\Theta = P_{\text{loss}} R_{\text{TH}}$$

- In general, the loss components other than P_R within the motor increase with the motor speed. Therefore, the maximum allowable P_R and the maximum continuous motor torque would decrease at higher speed, if the thermal resistance R_{TH} remains constant.

$$P_{\text{loss}} = P_R + \underbrace{P_{\text{FW}} + P_{\text{EH}} + P_s + P_{\text{stray}}}_{\sim \omega_m} \qquad P_R = k_2 T_{\text{em,rms}}^2$$

Criteria for Selecting Drive Components

12.2.3 Match between the motor and the power electronic converter

◆ In general, the power electronic converter provides a controlled voltage to the motor in order to control the motor current and the electromagnetic torque produced by the motor.

1) The current rating of the power electronic converter must be selected based on the rms and the peak values of the torque that the motor is required to supply.

Criteria for Selecting Drive Components

12.2.3 Match between the motor and the power electronic converter

2) To be able to quickly control the motor current and its torque, the output voltage v of the power electronic converter must be reasonably greater than the counter-emf e .

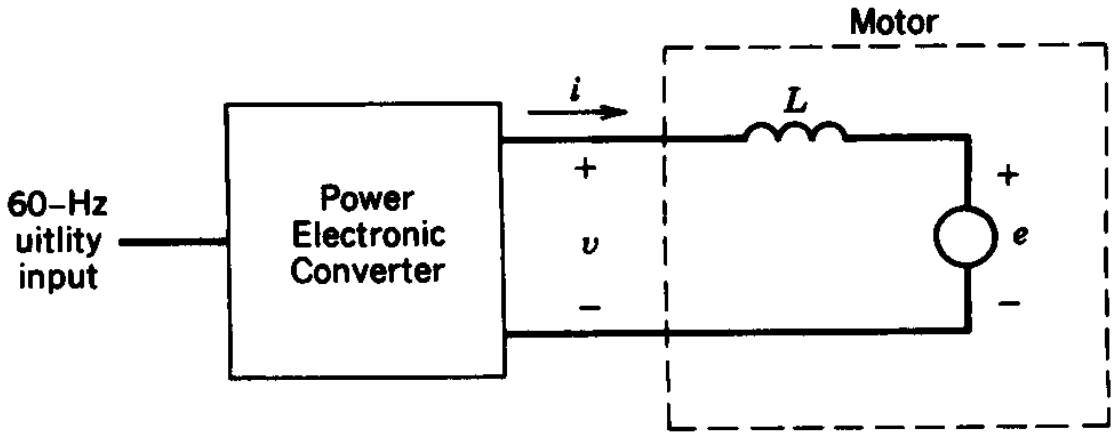


Figure 12-7 Simplified circuit of a motor drive.

Criteria for Selecting Drive Components

12.2.3 Match between the motor and the power electronic converter

• The magnitude of e in a motor increases linearly with the motor speed, with a constant flux in the air gap of the motor. Hence, the voltage rating of the power electronic converter depends on the maximum motor speed with a constant air-gap flux.

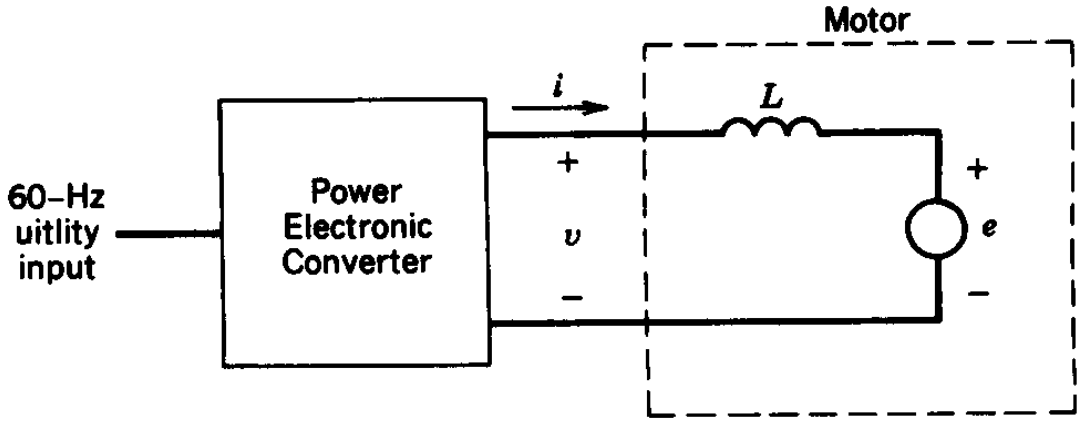


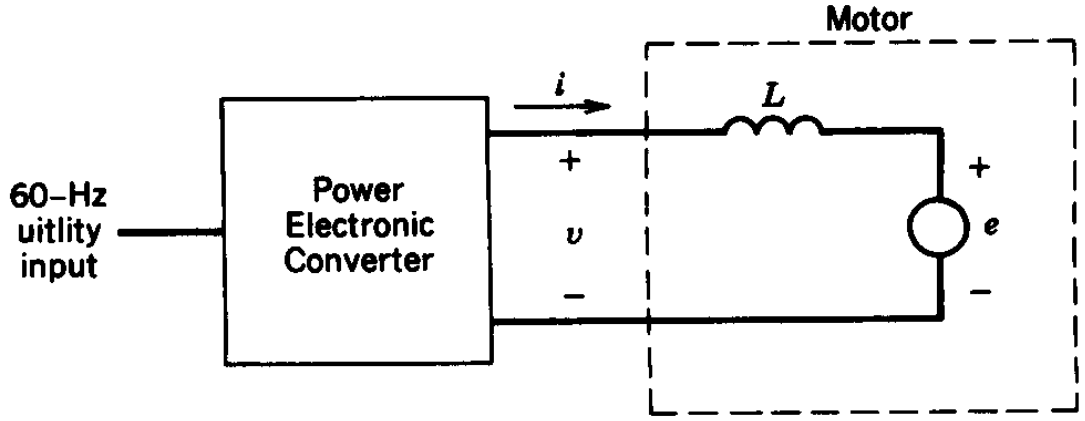
Figure 12-7 Simplified circuit of a motor drive.

Criteria for Selecting Drive Components

12.2.3 Match between the motor and the power electronic converter

3) The motor current should be able to respond quickly to the load demand, thus requiring L to be small. The motor current ripple should be small to minimize motor loss and the torque ripple, which requires L to be large.

A reasonable compromise must be made in selecting the motor inductance and the switching frequency.



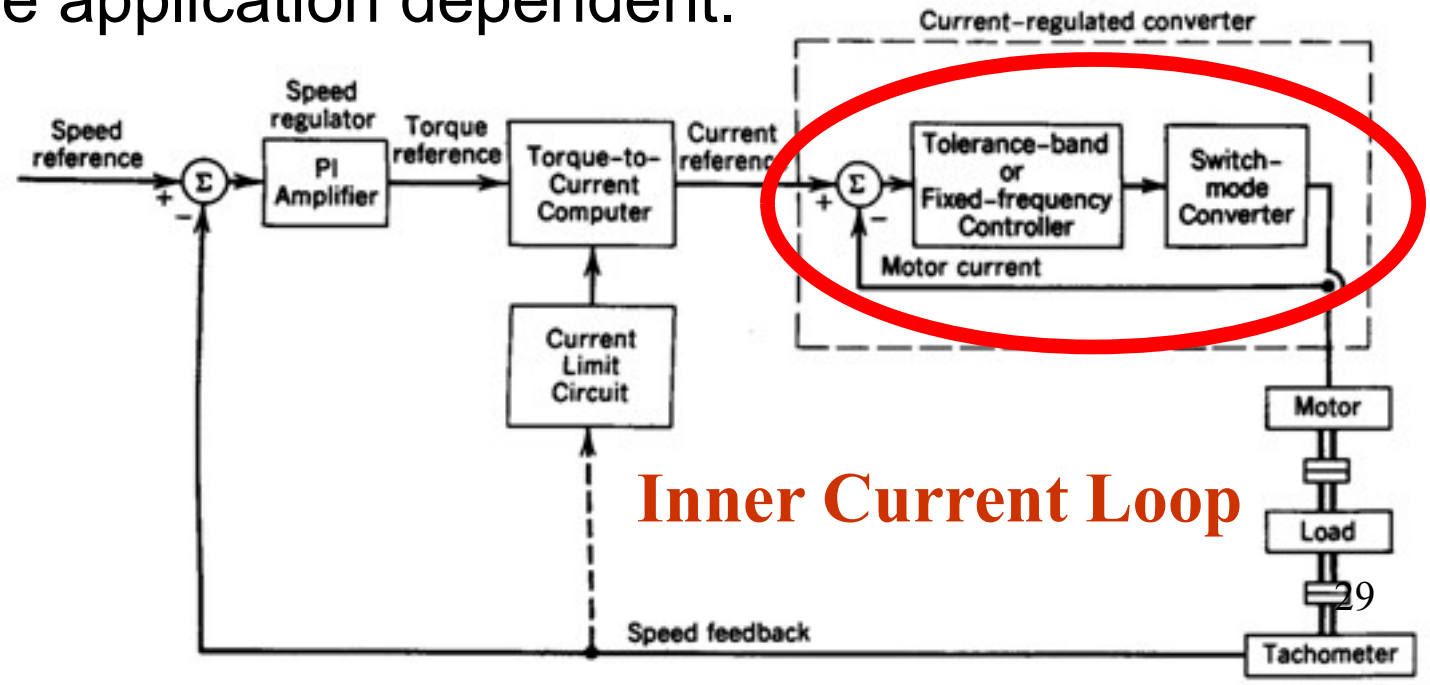
$$\frac{di}{dt} = \frac{v - e}{L}$$

Figure 12-7 Simplified circuit of a motor drive.

Criteria for Selecting Drive Components

12.2.4 Servo drive control and current limiting

- A very fast response to a sudden change in position or speed command would require a large peak torque and peak current.
- This may be prohibitive due to the cost of converters. The converter currents need be limited by the controller through two ways, which are application dependent.



Criteria for Selecting Drive Components

12.2.4 Servo drive control and current limiting

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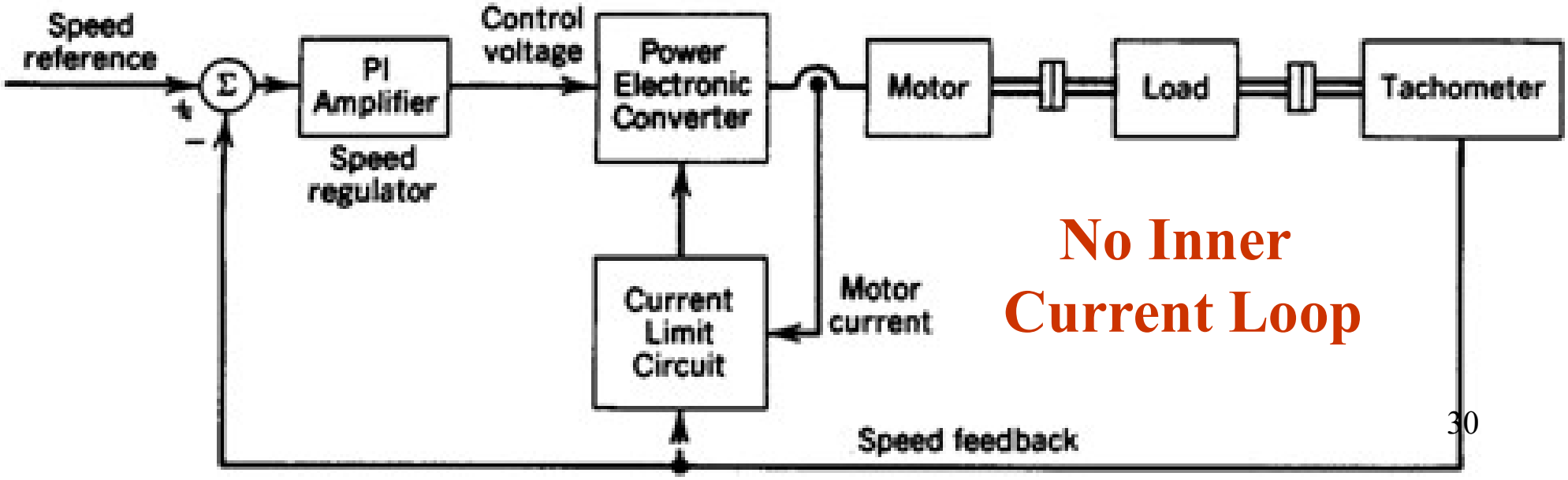

Criteria for Selecting Drive Components

12.2.5 Current limiting in adjustable-speed drives

- By providing ramp limiters, drive can be prevented from "triping" under sudden changes.
- The startup of induction motor by using VVVF (variable voltage variable frequency) control is an example of ramp limiters, which will be introduced later.

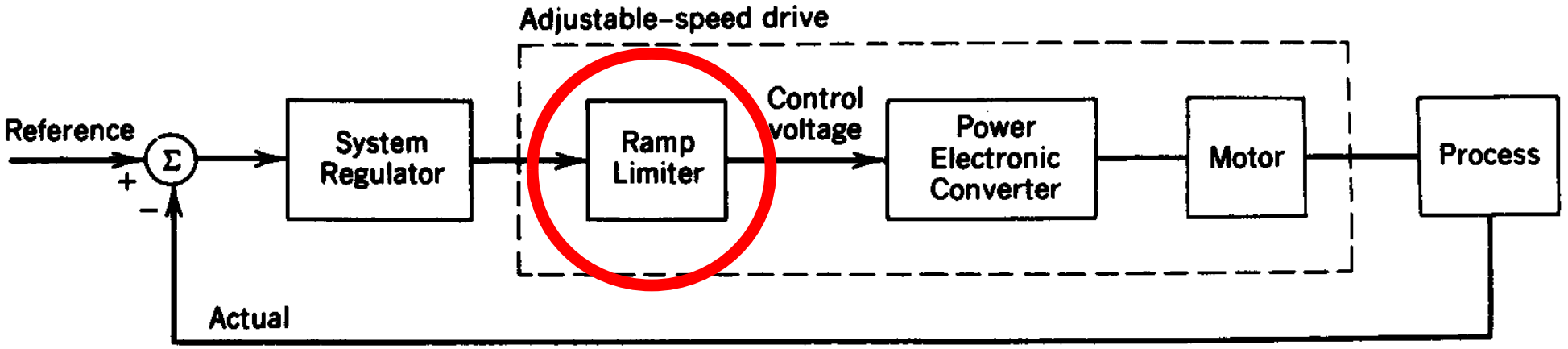

Figure 12-9 Ramp limiter to limit motor current.

References

- **Books**

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2) Philip T. Krein, Elements of power electronics, New York: Oxford University Press, 1998.

3) B.K. Bose, 现代电力电子学与交流传动（英文版）, 机械工业出版社

4) 黄立培, 电动机控制, 清华大学出版社

References

- **Journals and Conferences**

IEEE Transactions on Industrial Electronics

IEEE Transactions on Power Electronics

Applied Power Electronics Conference (APEC)

IEEE Industrial Electronics Conference (IECON)

IEEE Energy Conversion Congress and Exposition (ECCE)

Chap.12 Introduction to Motor Drives

Vocabulary (1)

1. motor	n.	电动机
2. motor drive	n.	电力传动,电机拖动
3. adjustable-speed drive	n.	变频调速
4. induction motor	n.	异步电动机
5. gear	n.	齿轮
6. feed screw	n.	丝杠
7. milling tool	n.	铣刀
8. windage	n.	风阻
9. eddy current	n.	涡流
10. hysteresis	n.	磁滞
11.lamination	n.	铁心
12.stray	n.	杂散
13.counter-emf	n.	反电势
14.ramp	n.	斜坡
15.tolerance-band	n.	公差带
16.tachometer	n.	转速表

Chap.12 Introduction to Motor Drives

Vocabulary (2)

17.armature winding	n.	电枢绕组
18.commutator	n.	换向器
19.carbon brushes	n.	碳刷
20.back-emf	n.	反电势
21.kinetic energy	n.	动能
22.renewable	adj.	可更新,可恢复的
23.photovoltaic	adj.	光电的
24.robotics	n.	机器人技术
25.throttling valve	n.	节流阀
26.residential	adj.	住宅的
27.refrigeration	n.	制冷
28.ventilating	n.	通风，通风设备
29.blower	n.	吹风机
30.arc furnaces	n.	弧光电炉
31.induction furnaces	n.	感应电炉

Vocabulary (3)

32.welding	n.	焊接
33.traction	n.	牵引
34.locomotives	n.	机车，火车头
35.trolley	n.	电车
36.supplemental	adj.	追加的，补充的
37.shuttle	n.	航天飞机
38.quantitative	adj.	数量的，定量的
39.qualitative	adj.	性质上的，定性的
40.scope	n.	范围，余地
41.synthesize	vt.	综合，合成
42.strategy	n.	策略
43.interdisciplinary	adj.	跨学科间的
44.snubber	n.	缓冲器
45.converter	n.	变换器