# Stepper Motors

## Chapter 8
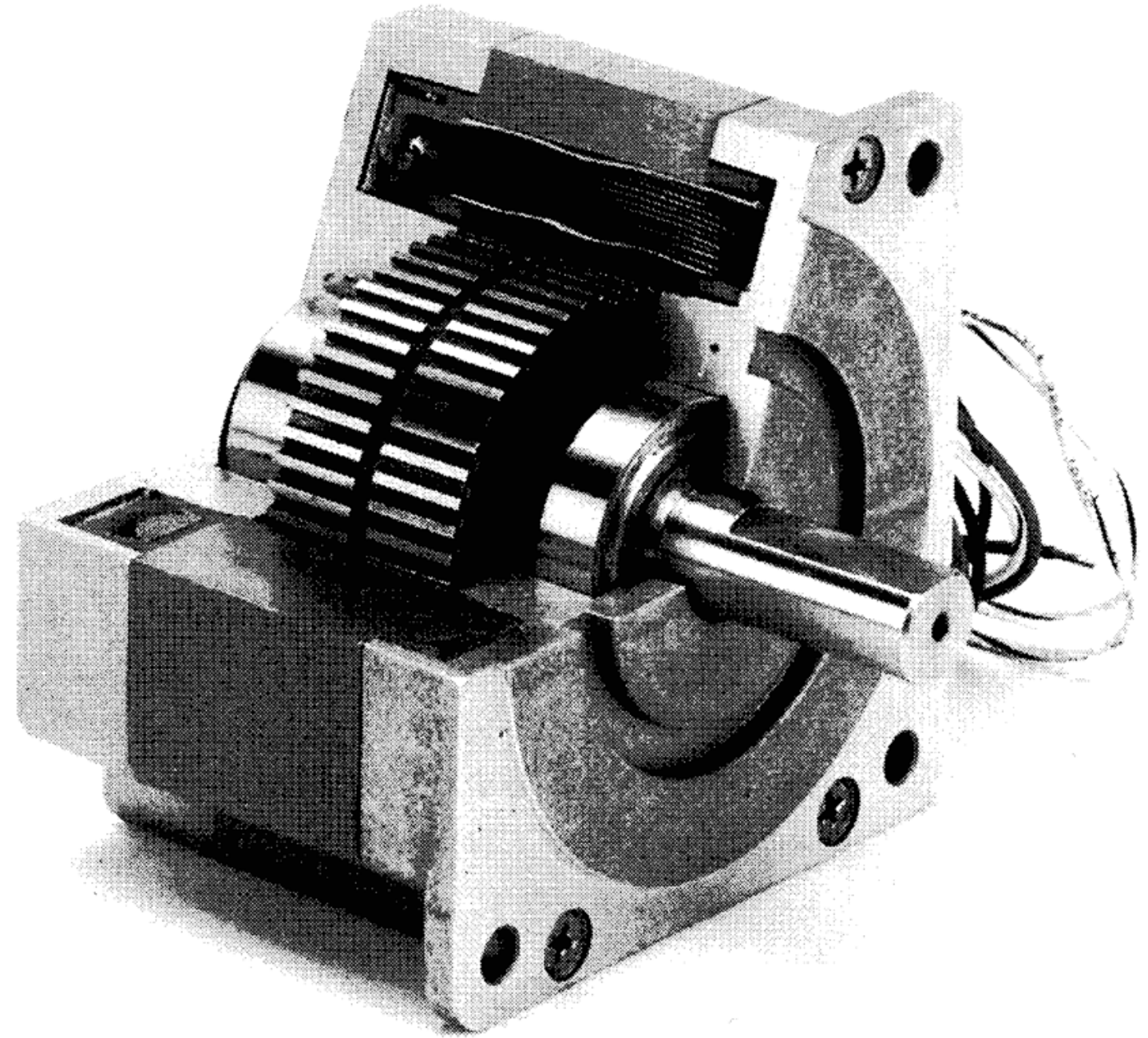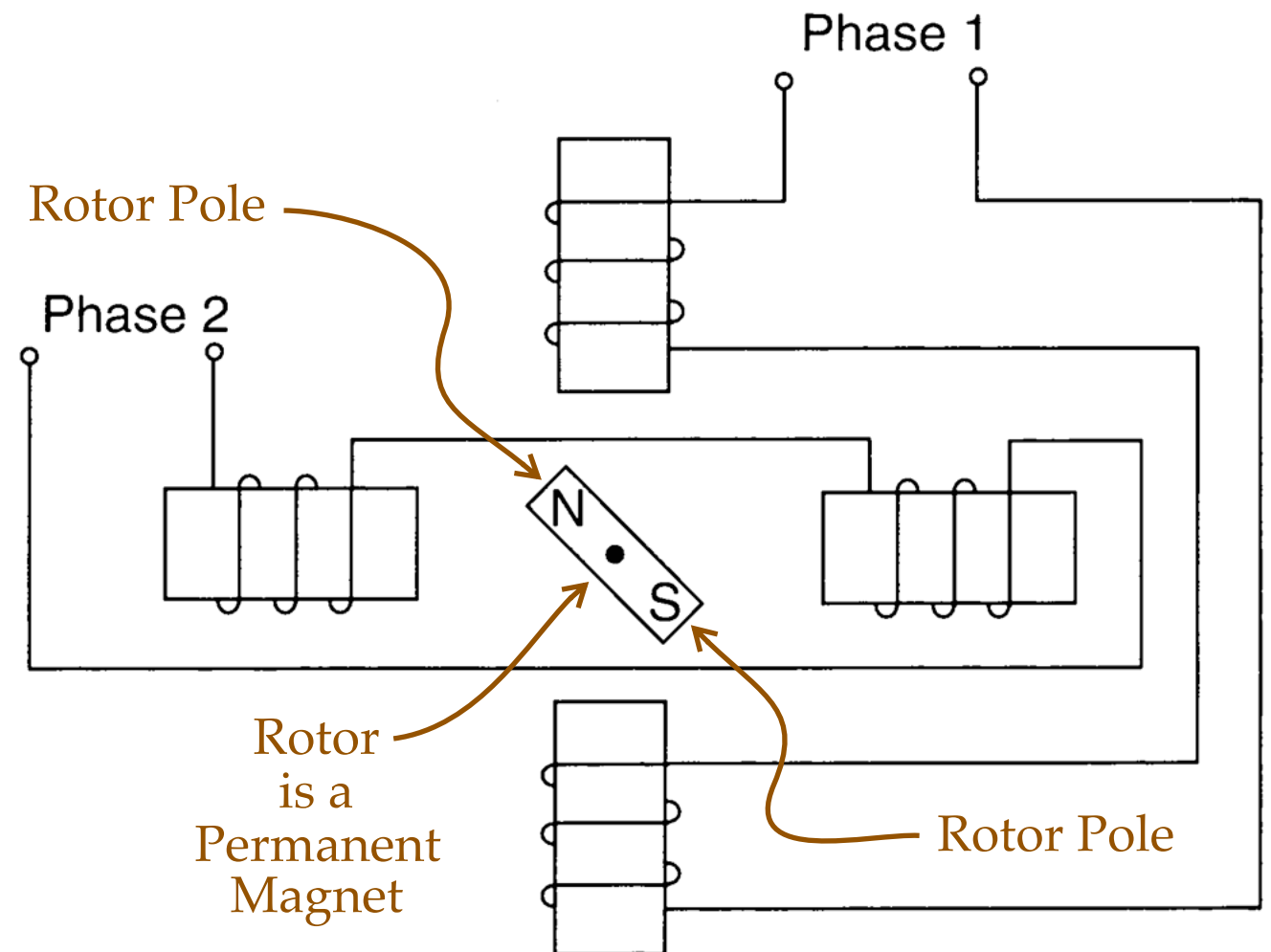
ME 473

Professor Sawyer B. Fuller

**Figure 8.1**
A commercial two-stack stepper motor.
(From Danaher Motion. With permission.)

**Figure 8.2**
Schematic diagram of a two-phase permanent-magnet stepper motor.

Ferromagnetic material

Phase 1

Phase 2

N · S

Rotor is a Permanent Magnet

**Figure 8.2**
Schematic diagram of a two-phase permanent-magnet stepper motor.
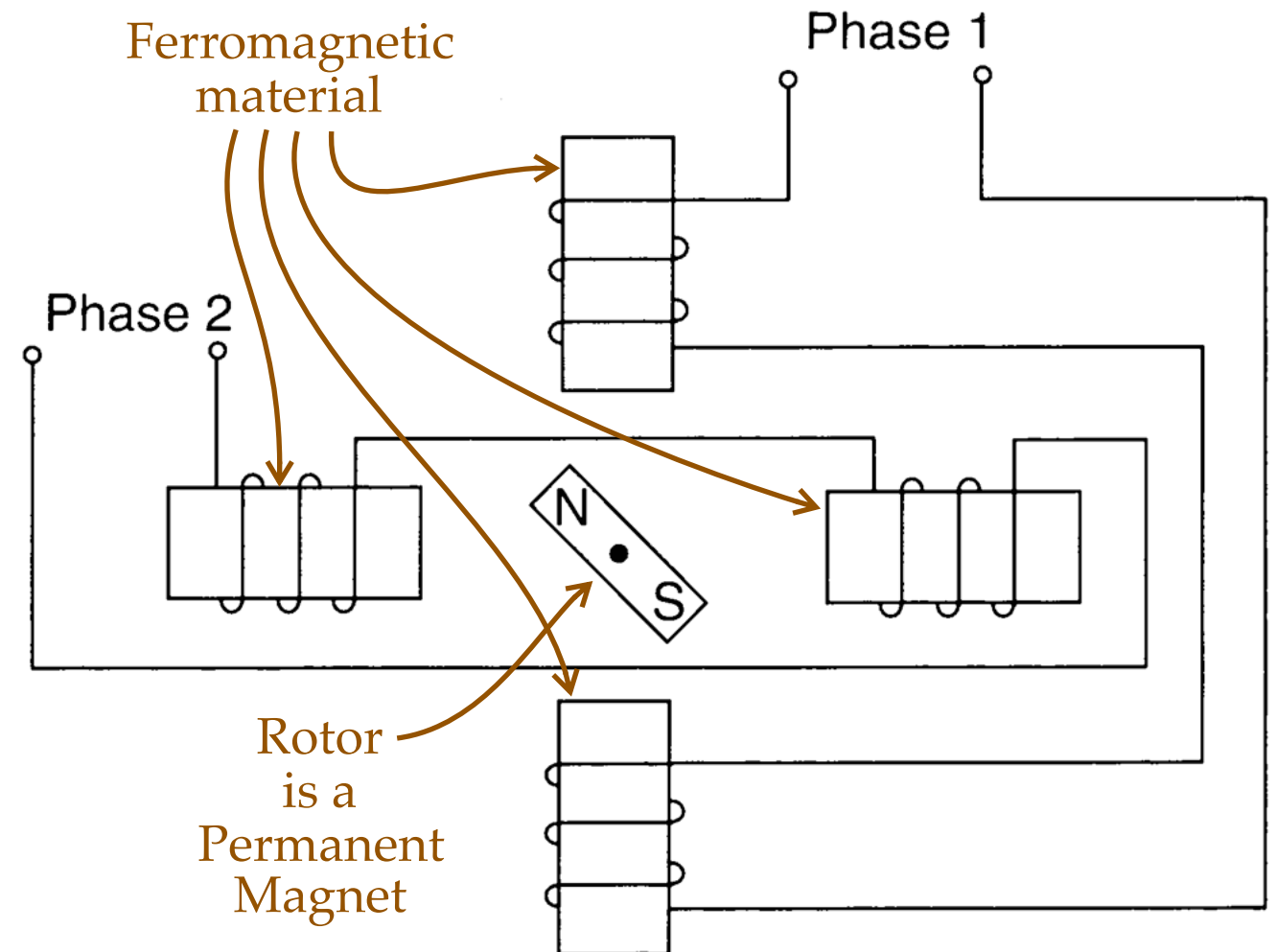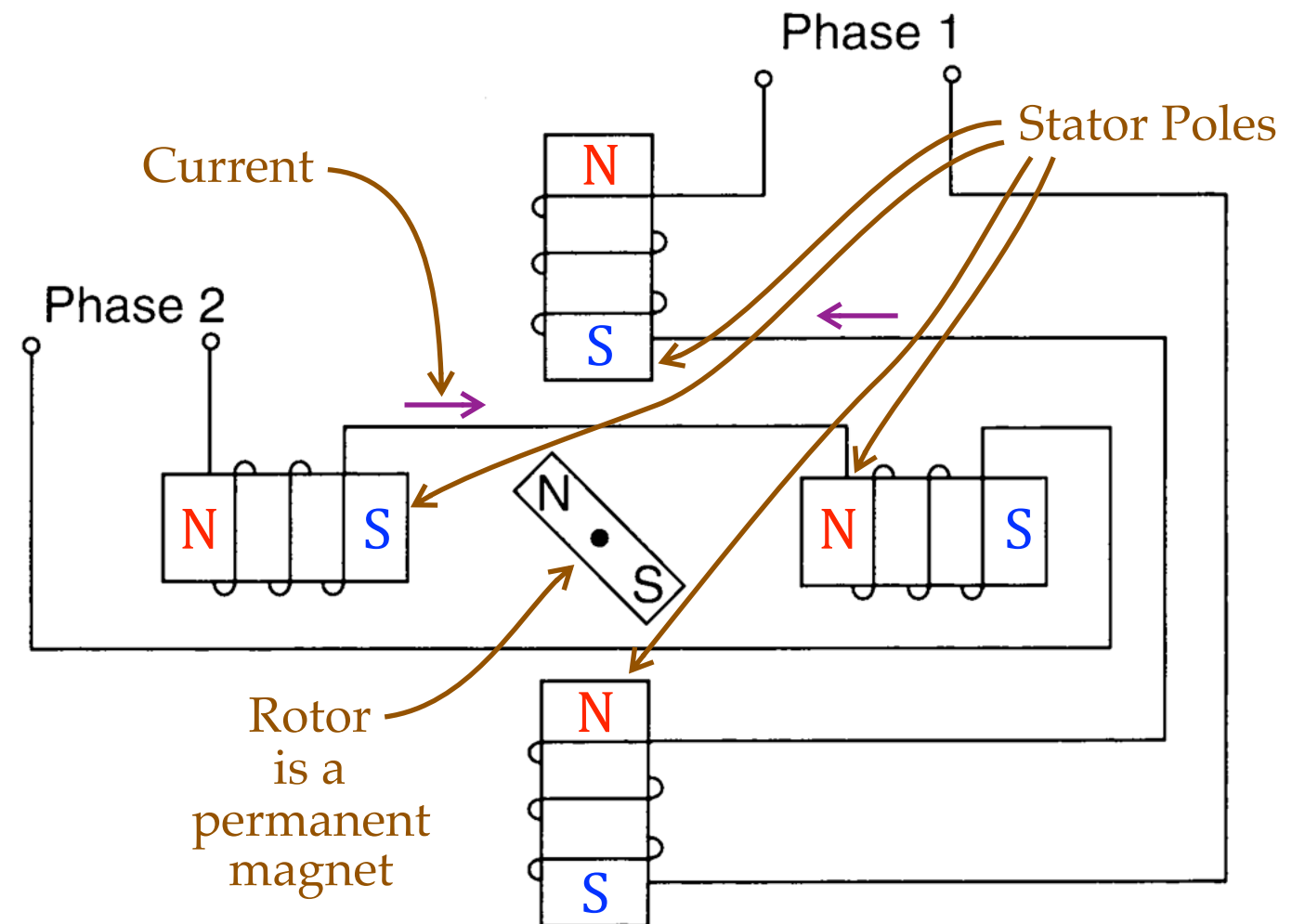
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**Figure 8.2**

Schematic diagram of a two-phase permanent-magnet stepper motor.

**Figure 8.2**

Schematic diagram of a two-phase permanent-magnet stepper motor.

Clockwise Torque on Rotor

Phase 1

Phase 2

N

S

N

S

N

S

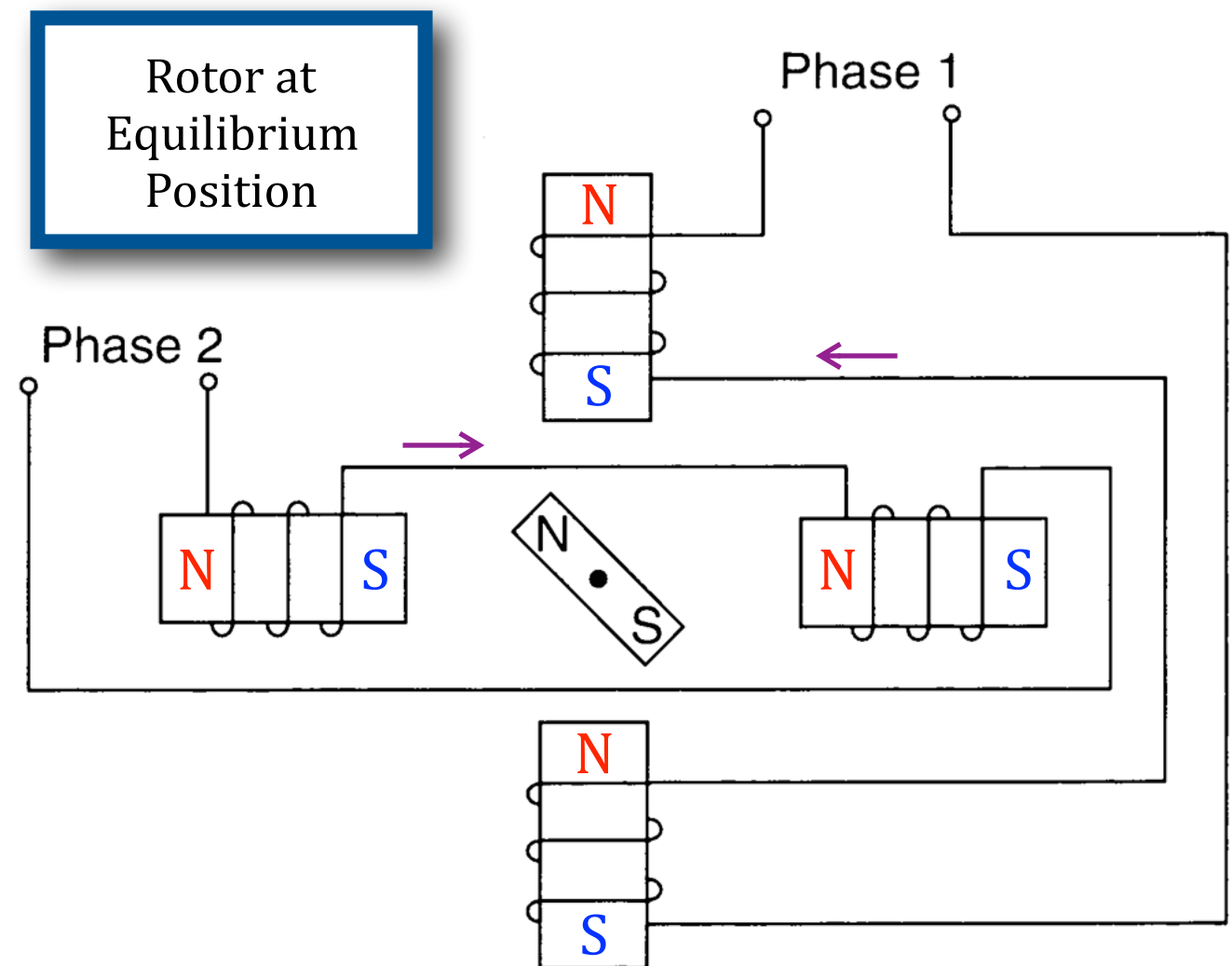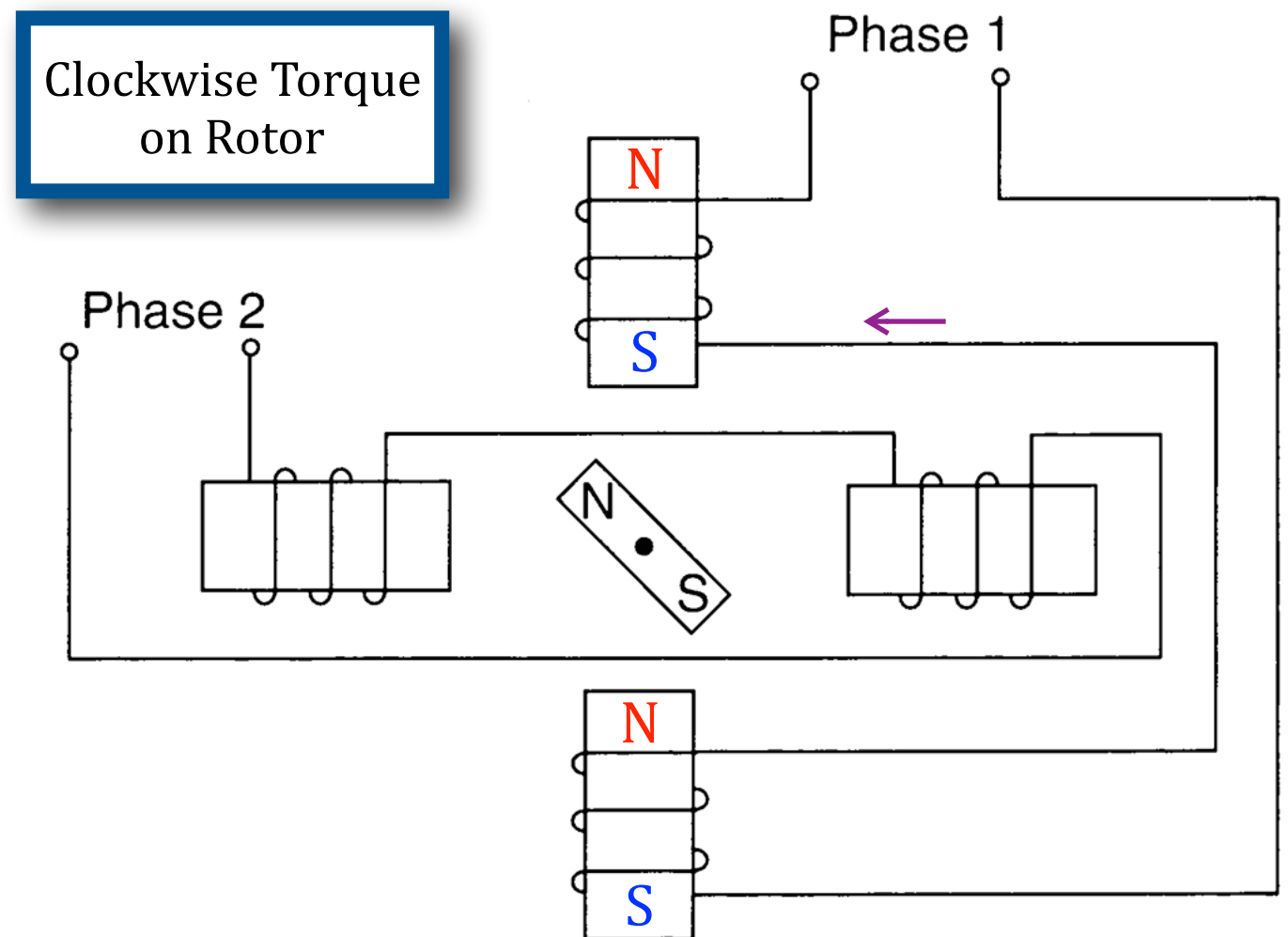**Figure 8.2**

Schematic diagram of a two-phase permanent-magnet stepper motor.

Clockwise Torque on Rotor is larger, but this requires current reversal

Phase 1

Phase 2

N

S

S    N

N    S

S    N

N

S
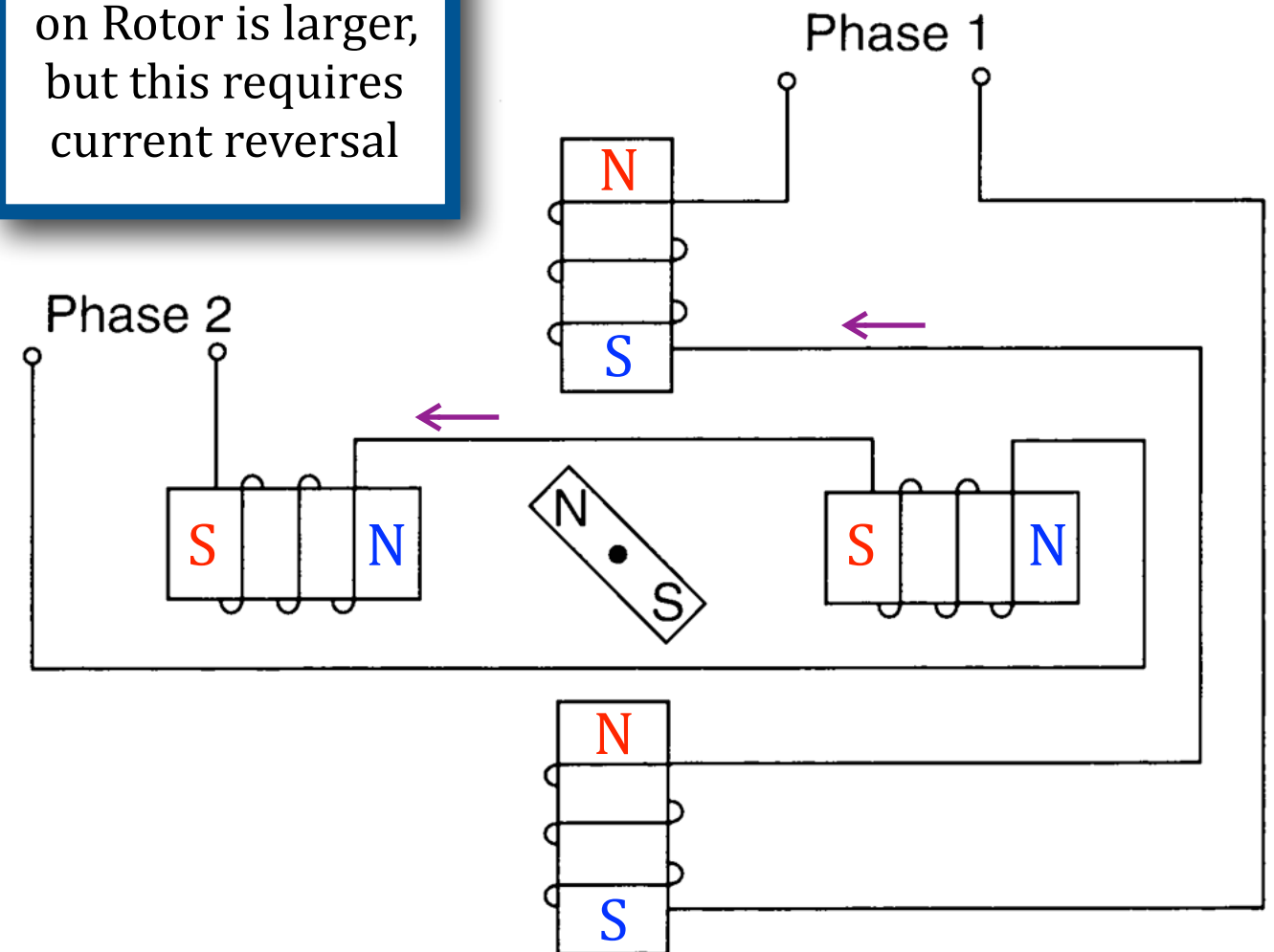
**Figure 8.2**
Schematic diagram of a two-phase permanent-magnet stepper motor.
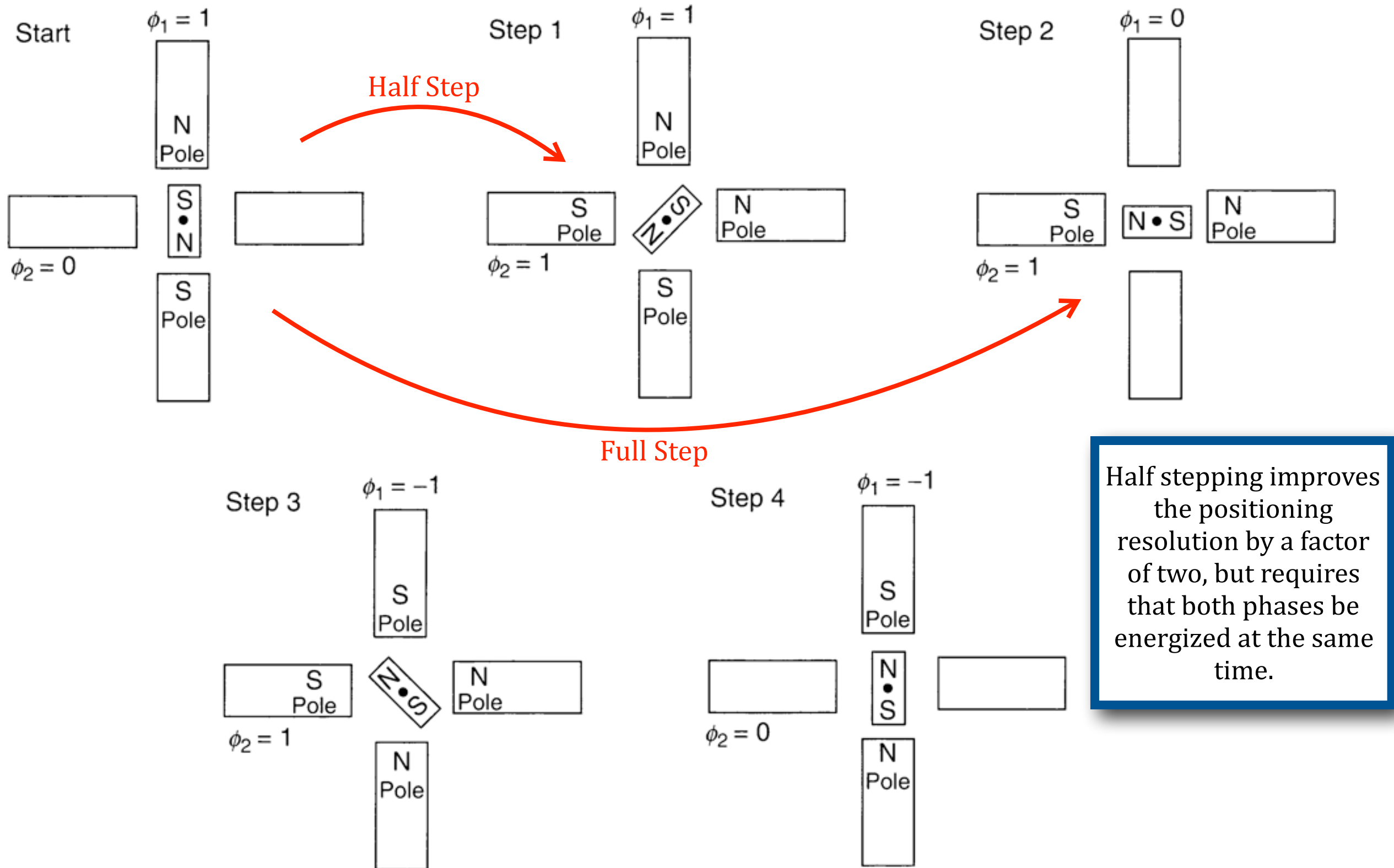
**Figure 8.3**
Stepping sequence (half stepping) in a two-phase PM stepper motor for clockwise rotation.

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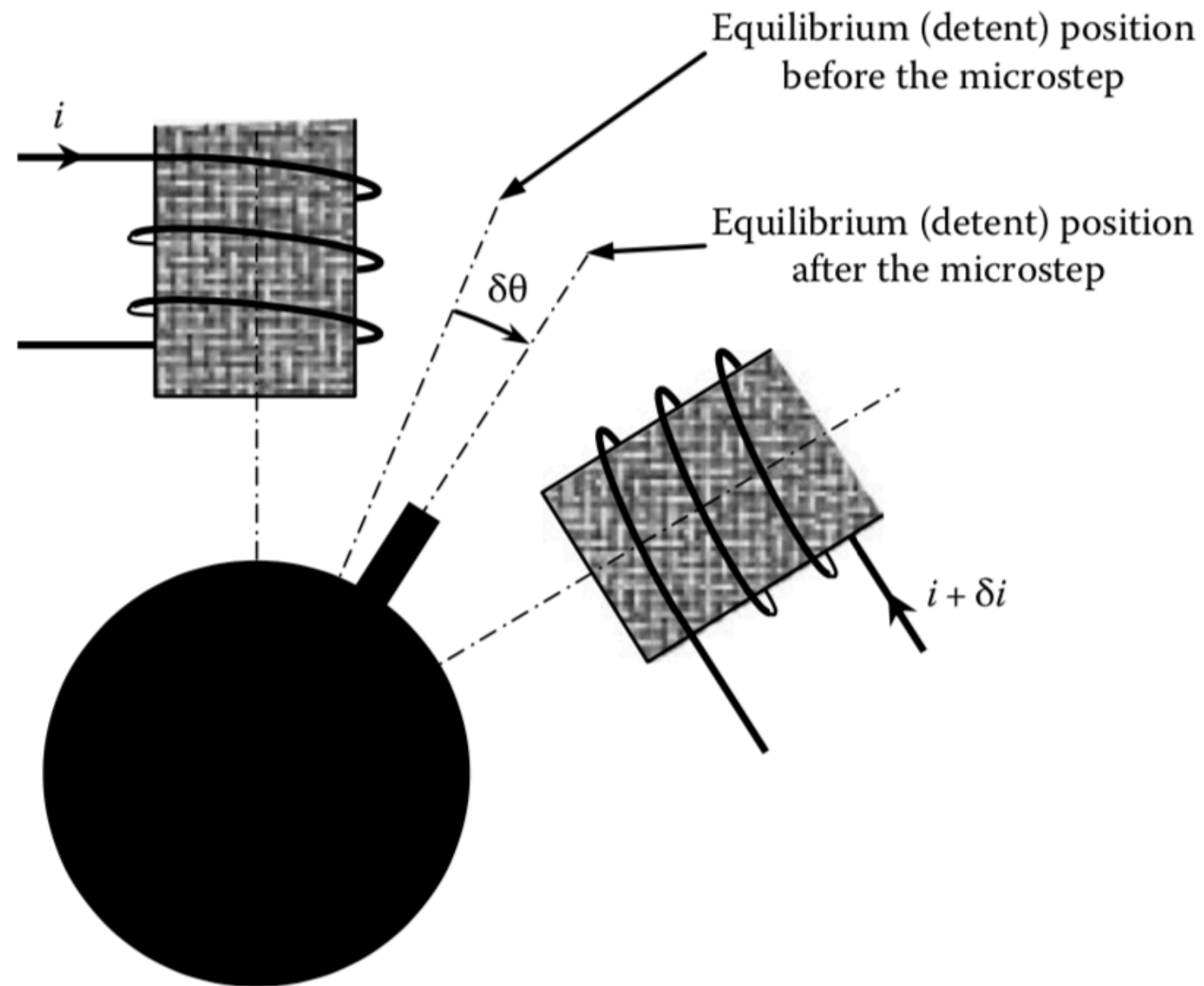
# Micro-stepping



**FIGURE 8.12**  The principle of microstepping.

Basic idea: instead of just *on* or *off*, precisely vary the phase current in small steps.
- Requires a more expensive motor controller, but gives a more precise control of angle.
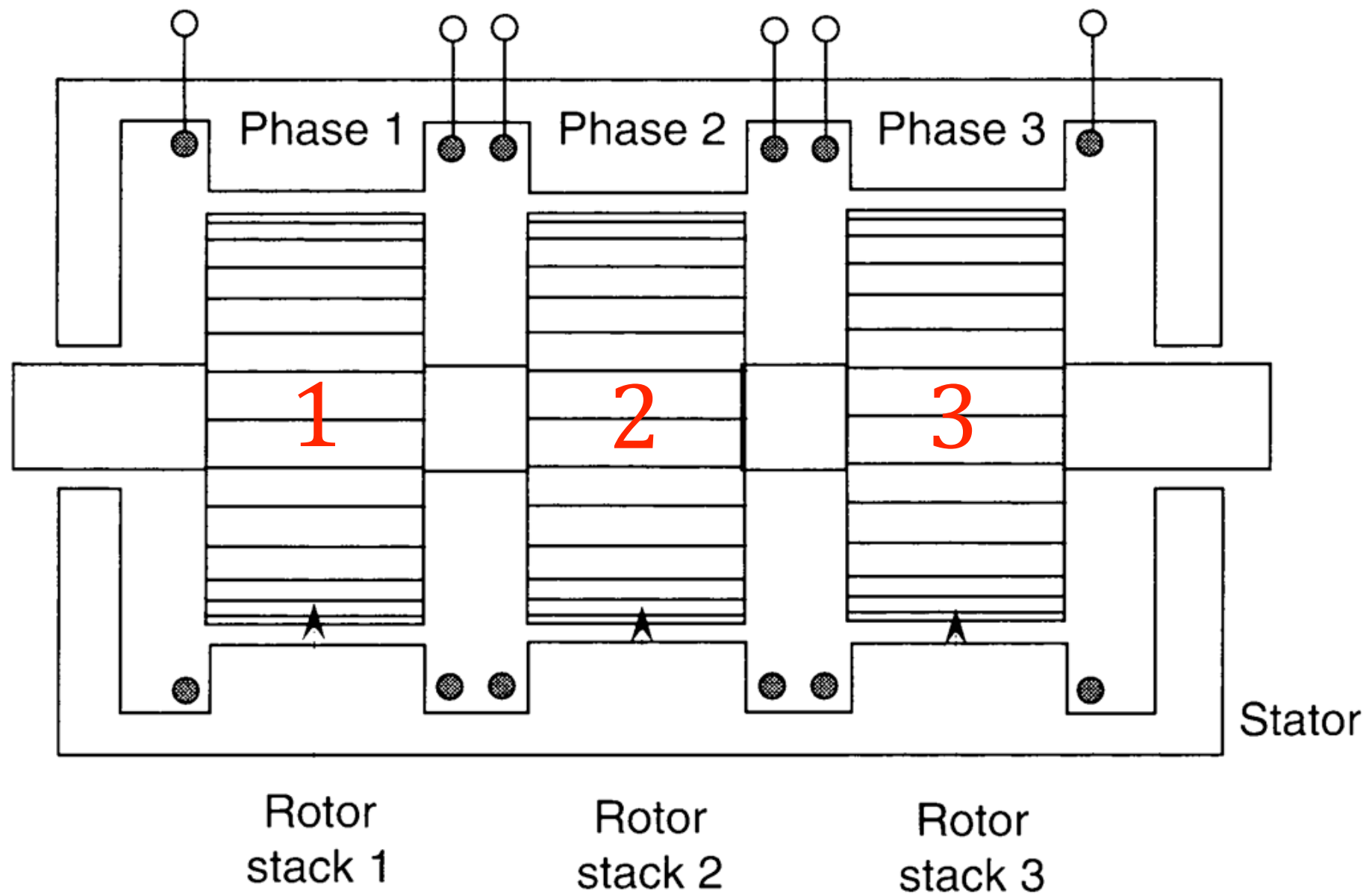
**Figure 8.13**
Longitudinal view of a three-stack (three-phase) stepper motor.

Stack #1 rotor teeth

Stack #2 rotor teeth
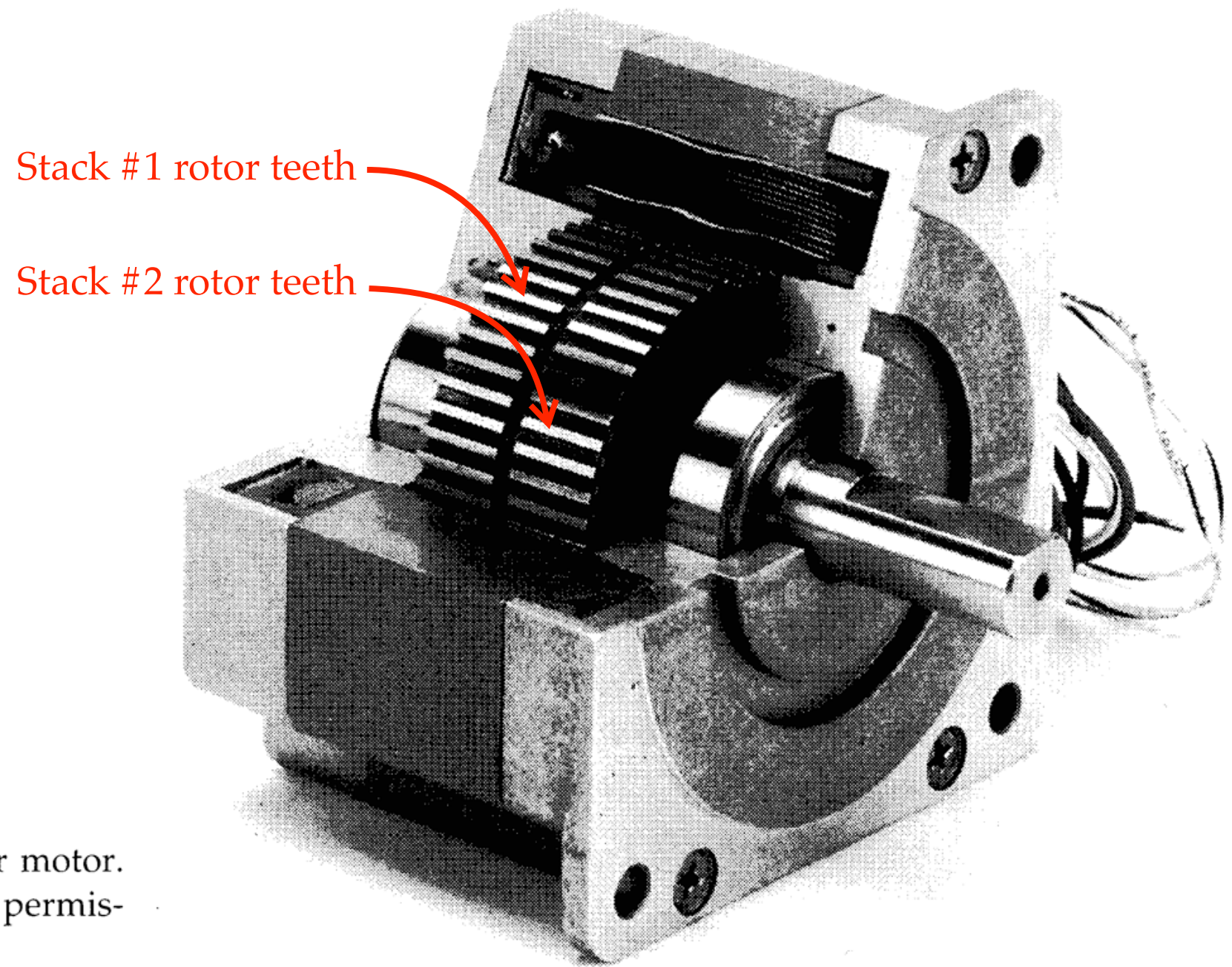
**Figure 8.1**

A commercial two-stack stepper motor. (From Danaher Motion. With permission.)

# A Brief Look at Stepper Motor Response Complexities
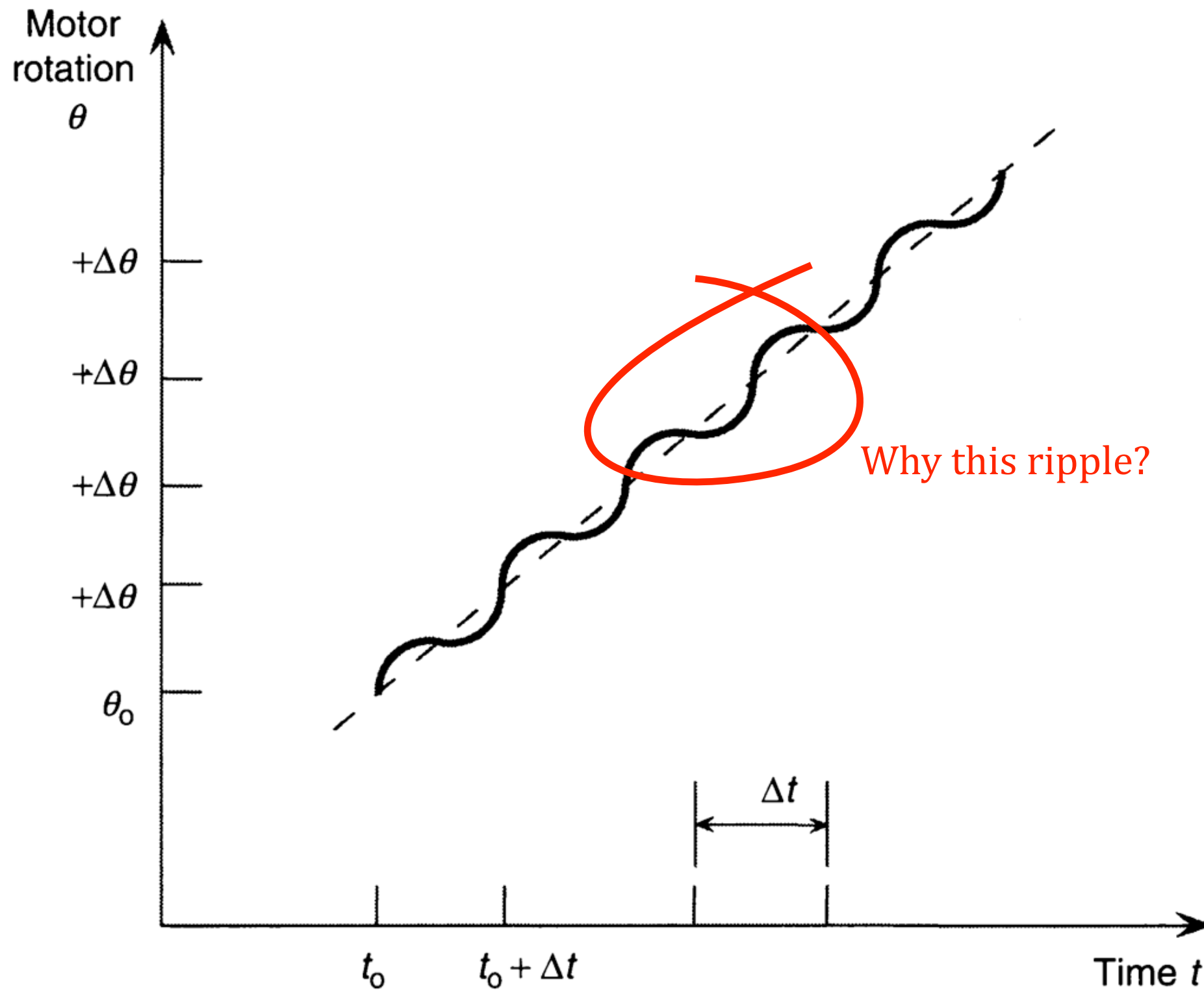
**Figure 8.23**
Typical slewing response of a stepping motor.
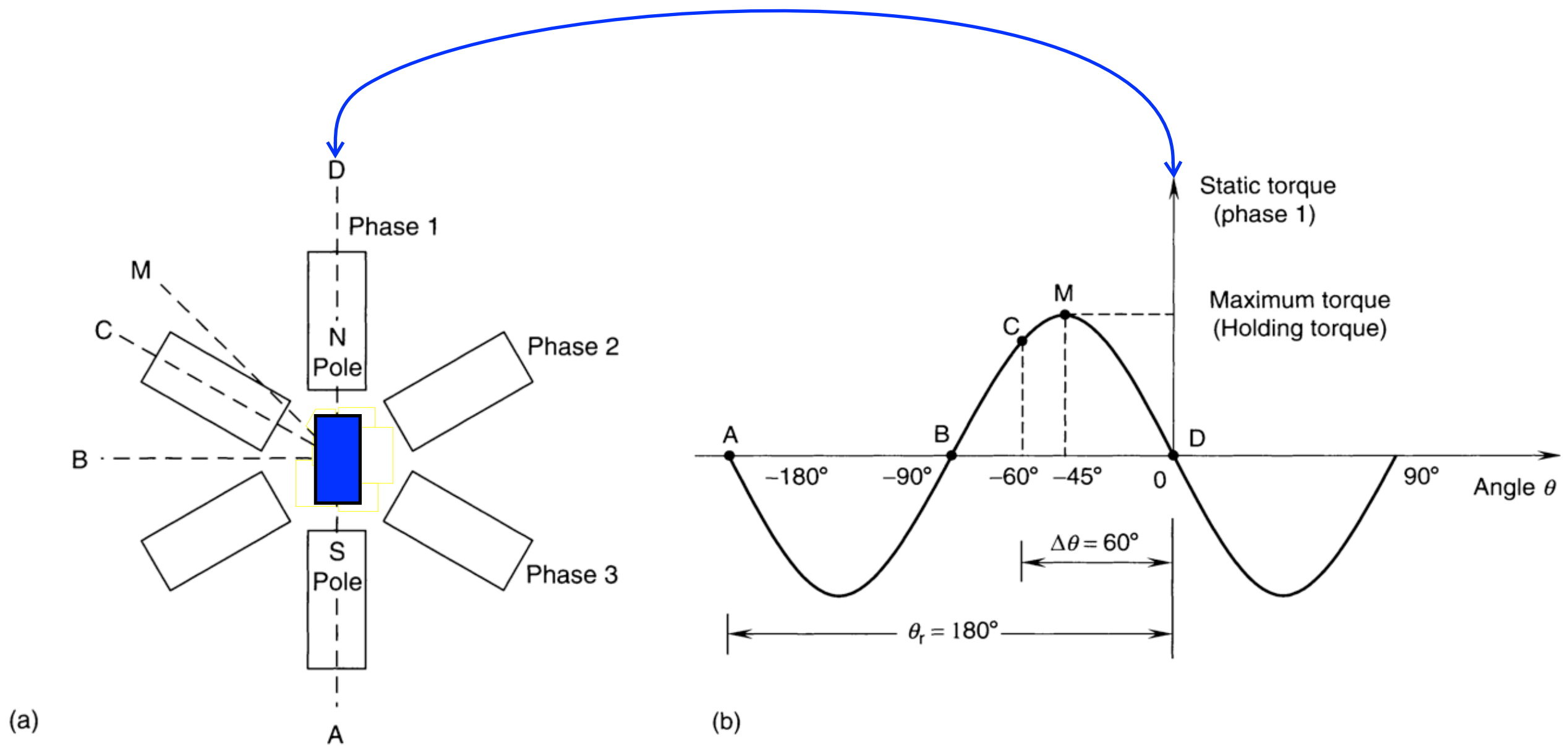
**Figure 8.22**
Static torque distribution of the VR stepper motor in Figure 6.5. (a) Schematic diagram. (b) Static torque curve for phase 1.
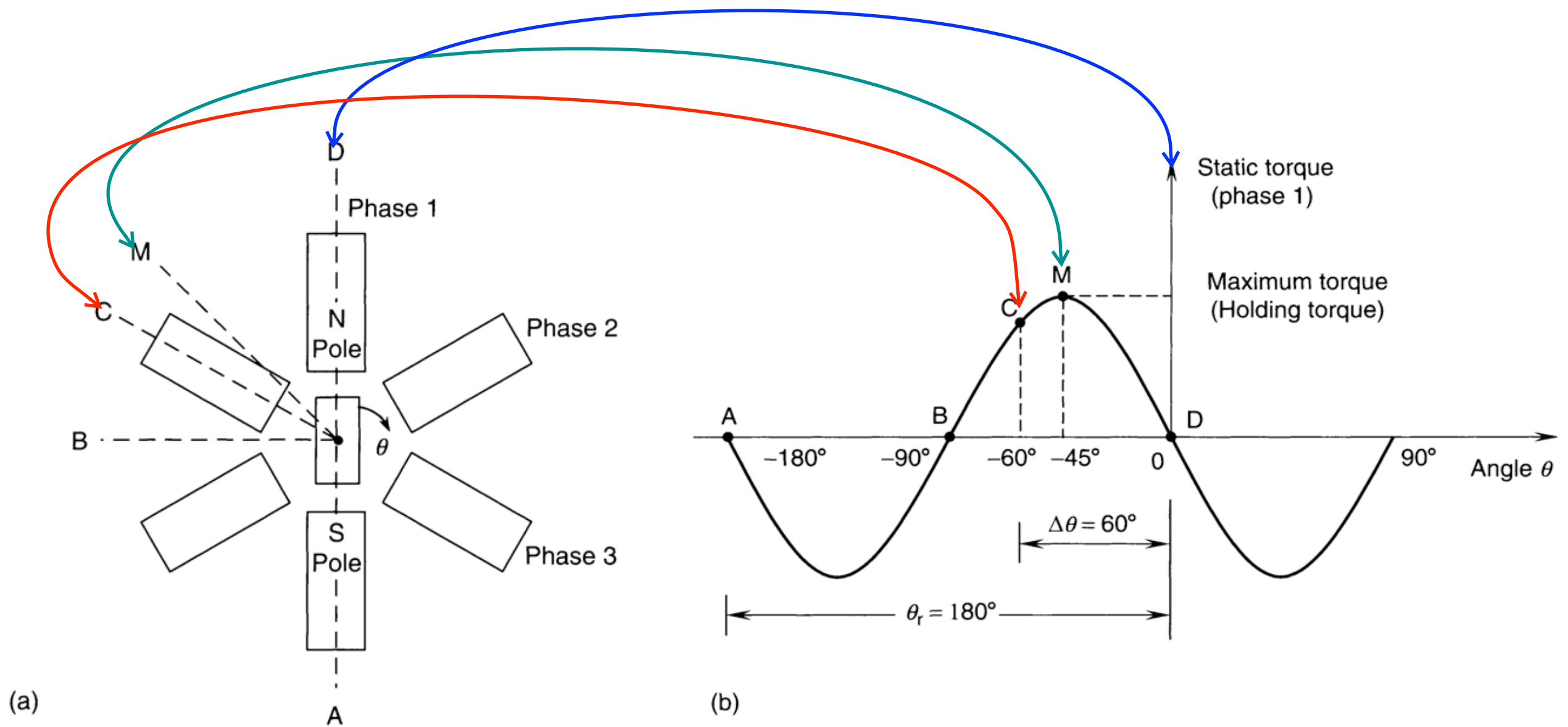
**Figure 8.22**
Static torque distribution of the VR stepper motor in Figure 6.5. (a) Schematic diagram. (b) Static torque curve for phase 1.
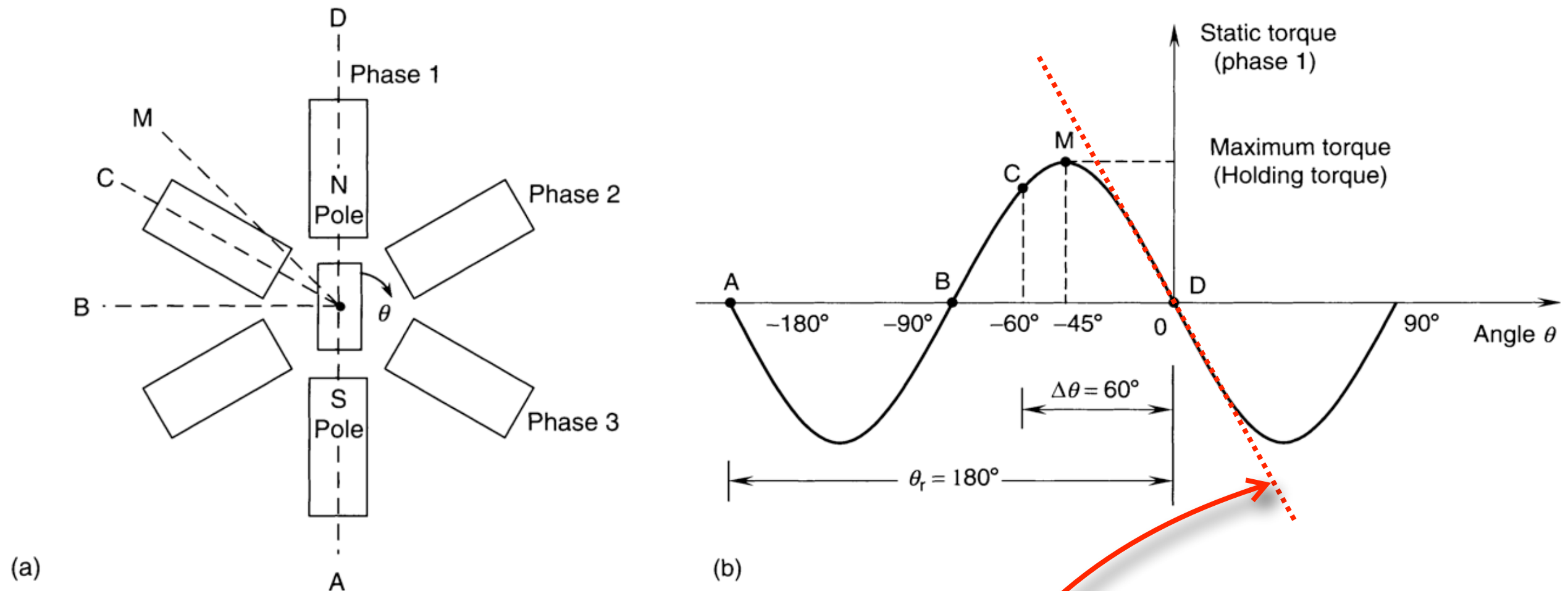
**Figure 8.22**
Static torque distribution of the VR stepper motor in Figure 6.5. (a) Schematic diagram. (b) Static torque curve for phase 1.

For sufficiently small displacements $\theta$ of the rotor from equilibrium position ($\theta = 0$), restoring torque is *proportional* to $\theta$.

Torque versus $\theta$ characteristic + low damping $\Rightarrow$ high overshoot in single-pulse response
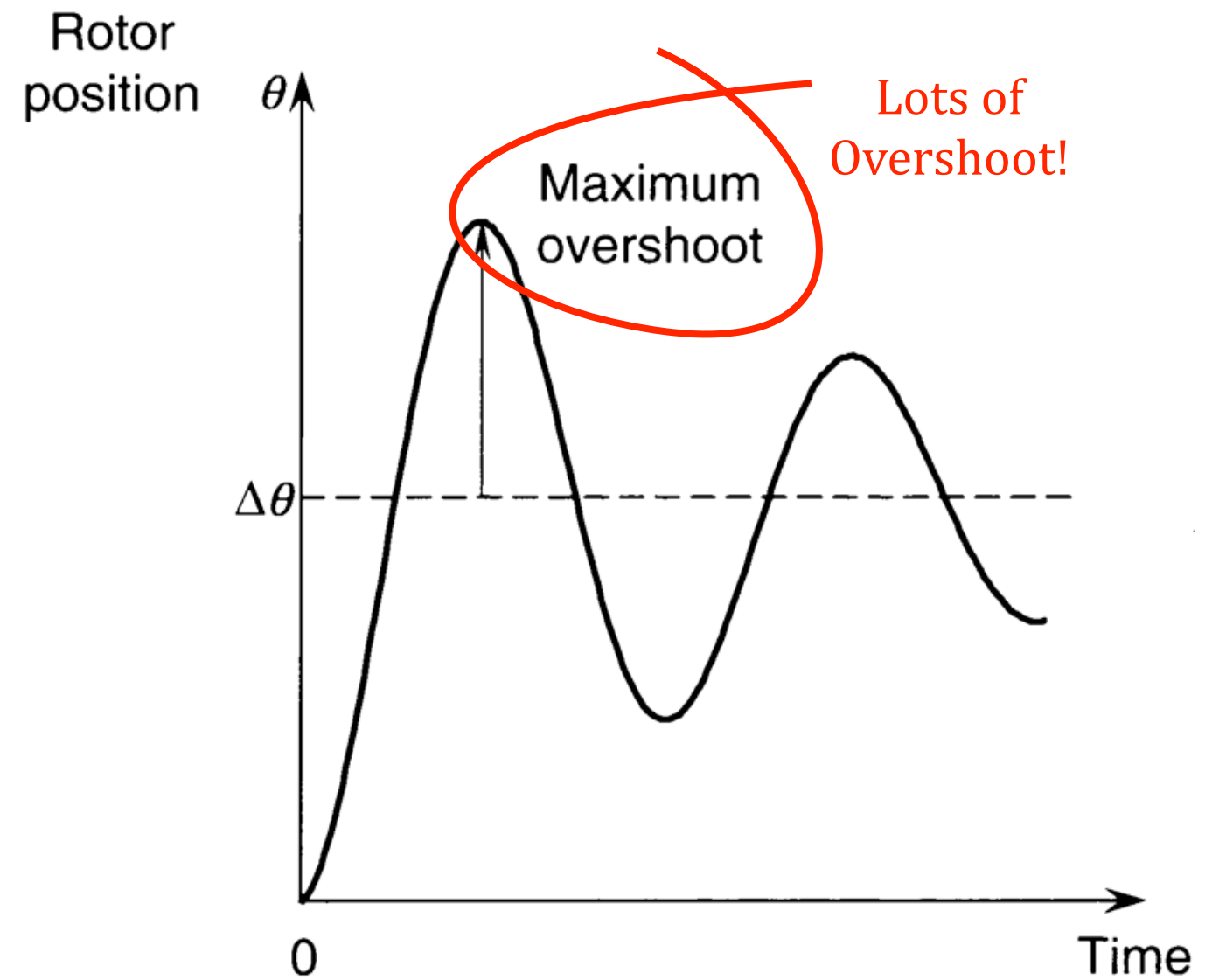
**Figure 8.21**
Single-pulse response of a stepper motor.
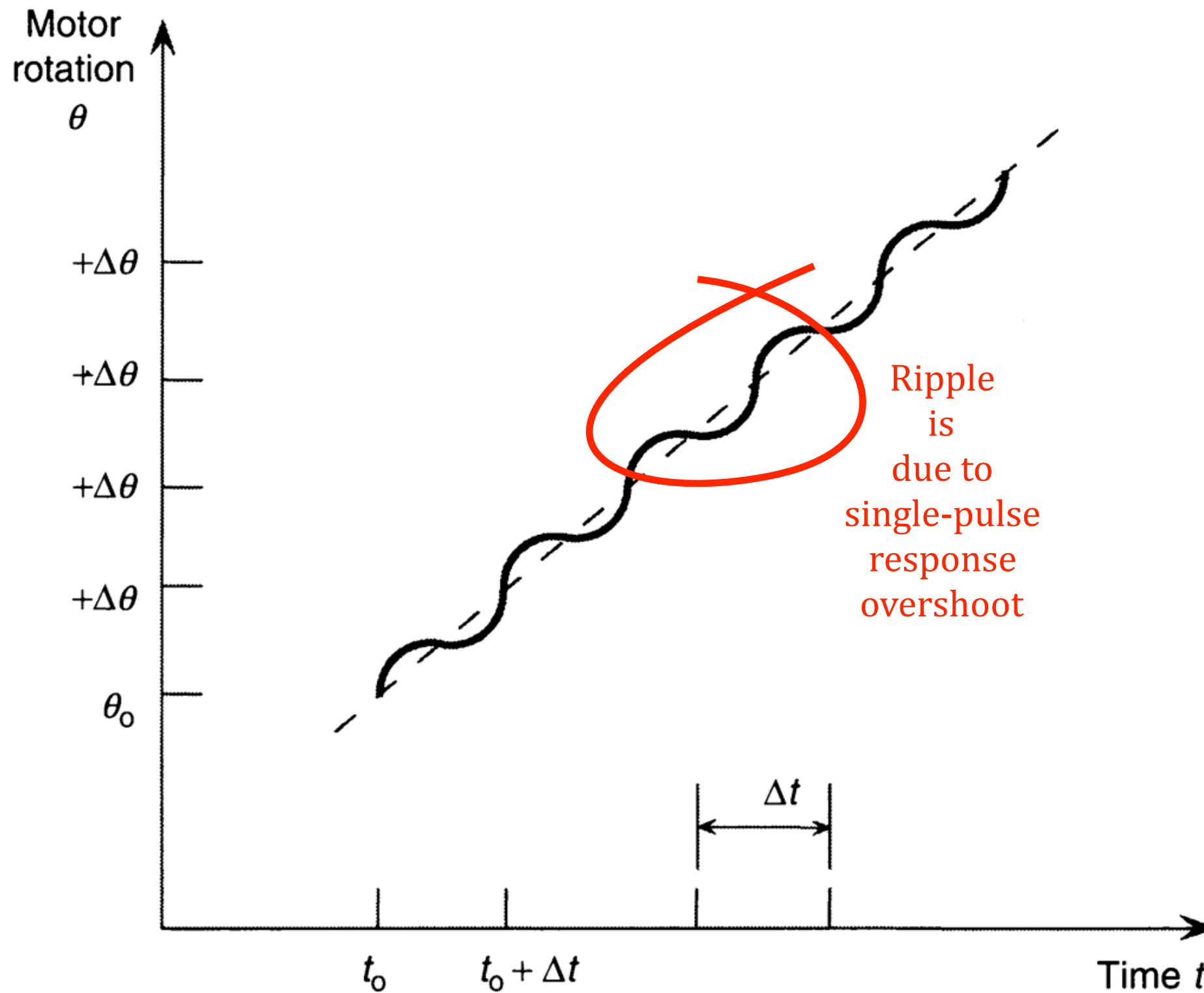
**Figure 8.23**
Typical slewing response of a stepping motor.

# Why are stepper motors not suitable for high-speed slewing operations?

## 8.3.2  Motor Time Constant and Torque Degradation

As the torque generated by a stepper motor is proportional to the phase current, it is desirable for a phase winding to reach its maximum current level as quickly as possible when it is switched on. Unfortunately, as a result of self-induction, the current in the energized phase does not build up instantaneously when switched on. As the stepping rate increases, the time period that is available for each step decreases. Consequently, a phase may be turned off before reaching its desired current level in order to turn on the next phase, thereby degrading the generated torque. This behavior is illustrated in Figure 8.19.
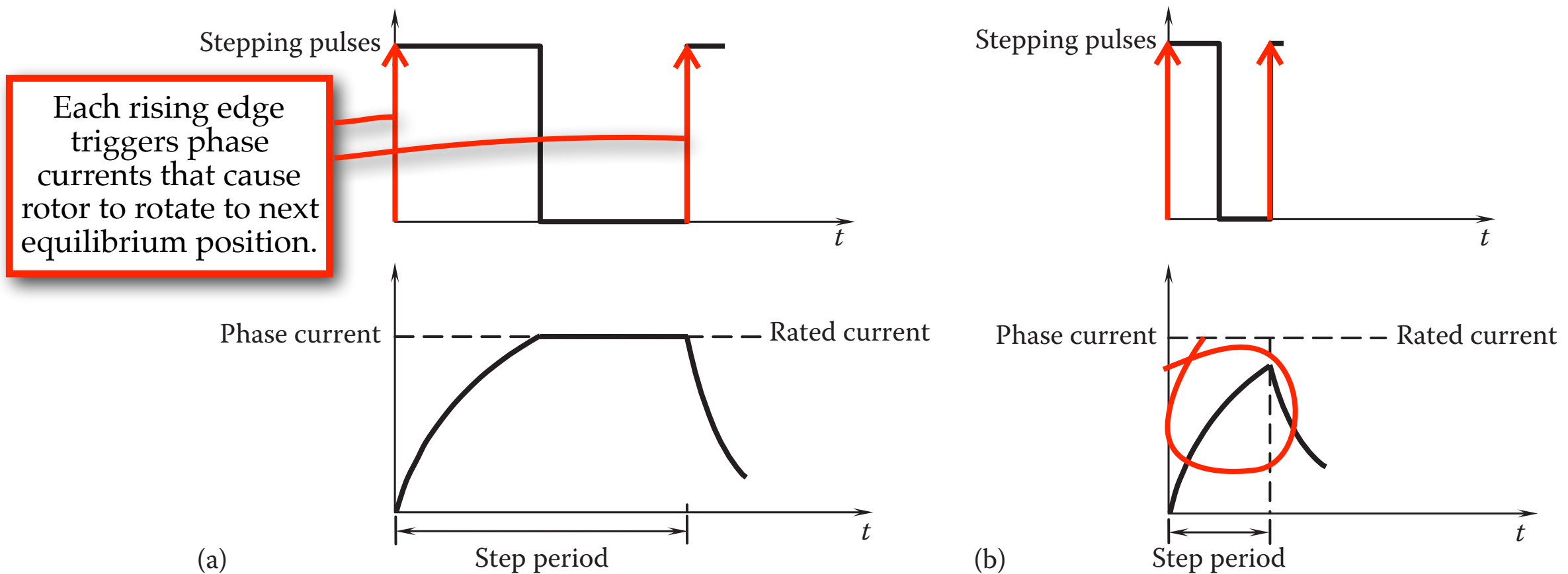
**Figure 8.19** Torque degradation at higher stepping rates due to inductance: (a) low stepping rate and (b) high stepping rate.

## 8.3.2 Motor Time Constant and Torque Degradation

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## 8.3.2 Motor Time Constant and Torque Degradation

The electrical time constant of a stepper motor is given by

$$\tau_e = \frac{L}{R} \qquad (8.21)$$

where

$L$ is the inductance of the energized phase winding

$R$ is the resistance of the energized circuit, including winding resistance

It is well-known that the current buildup is given by

$$i = \frac{v}{R}\exp(1 - t/\tau_e) \qquad (8.22)$$

where $v$ is the supply voltage. The larger the electrical time constant the slower the current buildup. The driving torque of the motor decreases due to the lower phase current. Also, because of self-induction, the current does not die out instantaneously when the phase is switched off. The instantaneous voltages caused by self-induction can be high, and they can damage the translator and other circuitry. The torque characteristics of a stepper motor can be improved (particularly at high stepping rates) and the harmful effects of induced voltages can be reduced by decreasing the electrical time constant. A convenient way to accomplish this is by increasing the resistance $R$. But we want this increase in $R$ to be effective only during the transient periods (at the instants of switch-on and switch-off). During the steady period, we like to have a smaller $R$, which will give a larger current (and magnetic field), producing a higher torque, and furthermore lower power dissipation (and associated mechanical and thermal problems) and reduction of efficiency. This can be accomplished by using a diode and a resistor $\Delta R$, connected in parallel with the phase winding, as shown in Figure 8.20. In this case, the current will loop through $R$ and $\Delta R$, as shown, during the switch-on and switch-off periods, thereby decreasing the electrical time constant to

Details in Sections 8.3.2, but no coverage of those details in homework or exams.

$$\tau_e = \frac{L}{R + \Delta R} \qquad (8.23)$$

The advantages of stepper motors include the following:

1. Position error is noncumulative. A high accuracy of motion is possible, even under open-loop control.
2. The cost is relatively low. Furthermore, considerable savings in sensor (measuring system) and controller costs are possible when the open-loop mode is used.
3. Because of the incremental nature of command and motion, stepper motors are easily adoptable to digital control applications.
4. No serious stability problems exist, ~~even under open-loop control~~.
5. Torque capacity and power requirements can be optimized and the response can be controlled by electronic switching.
6. Brushless construction has obvious advantages (see Chapter 9).

The disadvantages of stepper motors include the following:

1. They are low-~~speed~~ _torque_ actuators. The torque capacity is typically less than 15 N·m, which ~~may be~~ _is_ low compared to what is available from torque motors.
2. They have limited speed (limited by torque capacity and by pulse-missing problems due to faulty switching systems and drive circuitry).
3. They have high vibration levels due to stepwise motion.
4. Large errors and oscillations can result when a pulse is missed under open-loop control.
5. Thermal problems can be significant when operating at high speeds.