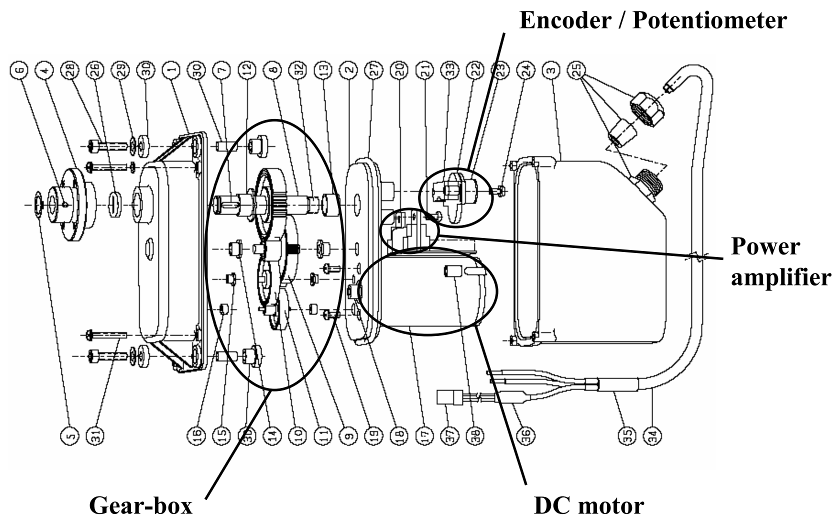
week	lecture	topics
10	Embedded Control Applications II	- Servo-motor control - Stepper motor control

Control of a DC servo-motor

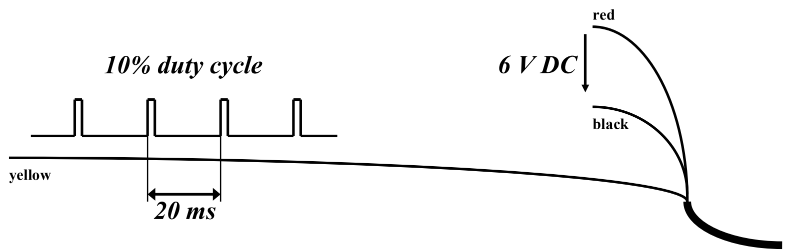
- The *control of a DC servo motor* is another common task in robotics / mechatronics; DC servo-motors combine regular DC-motors with a gear-box and an encoder/potentiometer to form a position control loop
- Being *position controlled*, the drive shaft of a servo-motor can only assume a limited range of angular positions (typically ±90° or less)
- The set-point is a *Pulse Width Modulated (PWM)* signal with a period of commonly around 20 ms and duty cycles of 2% to 10% (~0.5 ms to ~2.5 ms)

Control of a DC servo-motor



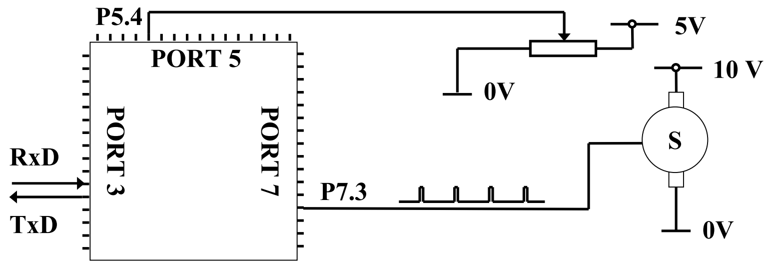
Control of a DC servo-motor

- Servo-motors have 3 wires: V_{supp}, V_{GND} and *signal*
- Only the *signal line* interfaces to the microcontroller – the current carrying supply lines need to be connected to a sufficiently powerful supply; typical supply voltages range between 6 V and 30 V



Control of a DC servo-motor

A small *DC servo-motor* is to be driven using an edge aligned PWM signal on P7.3 (period: 20 ms). The duty cycle is to be controlled by the analogue voltage applied to ADC channel 4, which is also logged on a terminal connected to ASC port S0 (57600 bps)



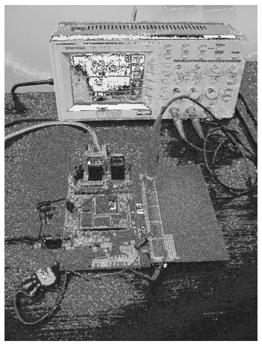
Control of a DC servo-motor

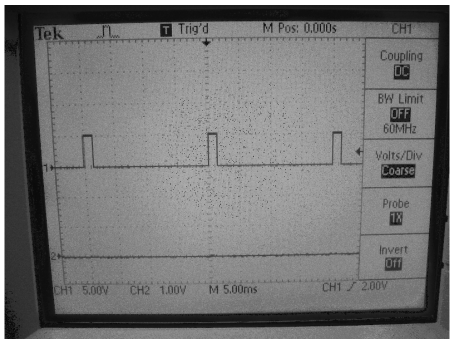
- This is essentially the program developed in lecture MP9; the period of the PWM signal has to be adjusted to 20 ms and the duty cycle needs limited to the range from 3 % (0.6 ms) to 10 % (2 ms)
- To produce the required 20 ms signal (50 Hz) the PWM module needs to be set up with a pre-scale factor of 1/64; a *12-bit resolution* is to be expected (mode: 0), i. e. $20 \cdot 10^{-3}/4096 \approx 4.88 \cdot 10^{-6}$ s ≈ 5 µs

Inp.Clk. (f_{CPU}/x) (Counter resol.)	PWM Mode	8-bit PWM Resolution	10-bit PWM Resolution	12-bit PWM Resolution	14-bit PWM Resolution	16-bit PWM Resolution
20 MHz/1 (50 ns)	0	78.13 KHz	19.53 KHz	4.88 KHz	1.22 KHz	305.2 Hz
	1	39.06 KHz	9.77 KHz	2.44 KHz	610.4 Hz	152.6 Hz
20 MHz/64 (3.2 µs)	0	1.22 KHz	305.2 Hz	76.29 Hz	19.07 Hz	4.77 Hz
	1	610.4 Hz	152.6 Hz	38.15 Hz	9.54 Hz	2.38 Hz

Control of a DC servo-motor

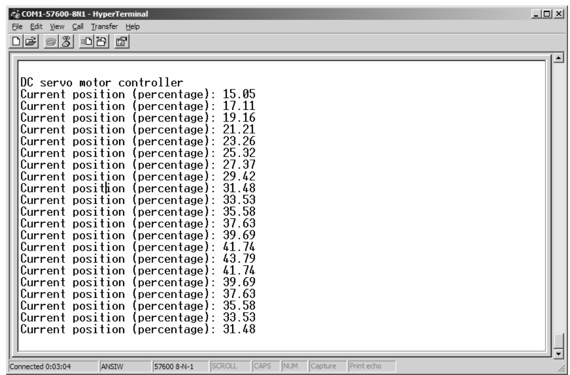
- Running the modified program on the C167 confirms a 20 ms period with pulses ranging from 0.6 ms (setting: 0 %) to 2 ms (setting: 100 %)





Control of a DC servo-motor

- The terminal logs the current position as a percentage of the range of admissible pulse widths



Control of a stepper motor [1]

- A *stepper motor* is an electromechanical device which converts electrical pulses into *discrete* mechanical movements
- The shaft or spindle of a stepper motor rotates in discrete step increments when *electrical command pulses* are applied to it in the *proper sequence*
- This sequence is directly related to the direction of rotation of the motor shaft; the *speed* of the rotation is directly related to the *frequency* of the applied pulse sequence

Control of a stepper motor

Stepper motors have the following characteristics:

- The rotation angle of the motor is predictably related to the input pulse pattern
- The motor has *full torque at stand-still* (if the windings are energized)
- *Precise* positioning and repeatability of movement; good stepper motors have an accuracy of 3 – 5 % of a step – this error is non-cumulative from step to step
- Excellent response to starting, stopping, reversing

Control of a stepper motor

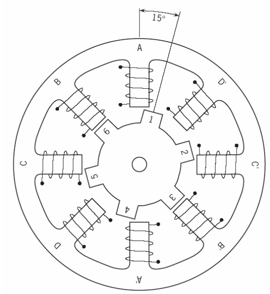
Stepper motors have the following characteristics:

- Stepper motors are *brushless* and thus very reliable; their life span usually only depends on their bearings
- They allow for accurate *open-loop* control; the position can be tracked simply by counting pulses
- They allow for very low speed synchronous operation with loads that are *directly coupled* to the shaft
- Improper control may cause resonance phenomena
- Difficult to operate at extremely high speeds

Control of a stepper motor

Three different kinds of stepper motors exist:

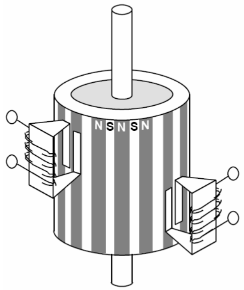
- *Variable-reluctance (VR)* stepper motors consist of a soft iron multi-toothed rotor and a wound stator
- Energizing the stator windings with DC currents causes the poles to be magnetized
- Rotation occurs when the rotor teeth are attracted to the energized stator poles



Control of a stepper motor

Three different kinds of stepper motors exist:

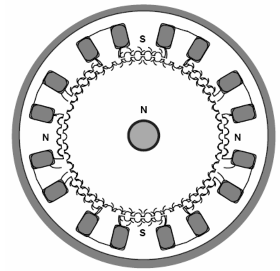
- *Permanent-Magnet (PM)* stepper motors ('tin can') are low cost and low resolution type motors – typical step angles range from 7.5° to 15°
- The rotor no longer has teeth (cf. VR motor), but is magnetized with alternating north and south poles
- The increased magnetic flux intensity gives the PM motor an improved torque characteristic



Control of a stepper motor

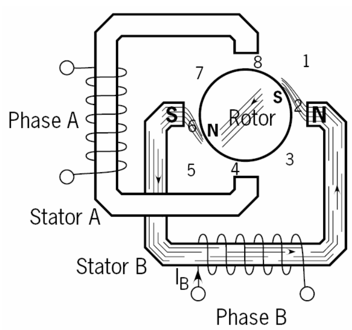
Three different kinds of stepper motors exist:

- *Hybrid (HB)* stepper motors combine the best features of PM and VR type stepper motors; step angles vary from 3.6° to 0.9° (100 – 400 steps per revolution)
- The rotor is teethed with an axially magnetized concentric magnet around the shaft
- The teeth on the rotor help guiding the magnetic flux; this leads to increased performance



Control of a stepper motor

- The stator windings need to be energized in such a way as to generate a *rotating magnetic field;* the rotor follows this field due to magnetic attraction
- Two-phase example: Energizing the windings using a *B-A-B-A-B-…* pattern leads to clockwise rotation
- The rotational speed depends on the frequency of the alternating sequence

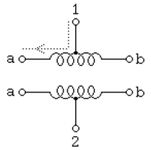


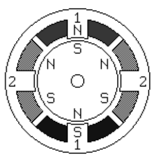
Control of a stepper motor

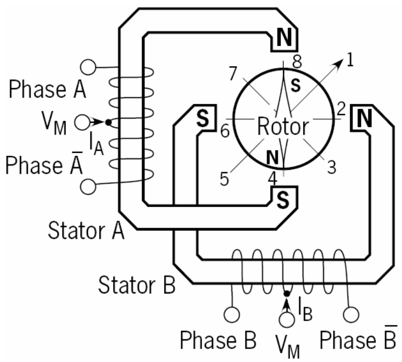
- The *torque* of a stepper motor depends on the step rate as well as the intensity of the magnetic flux in the windings which, in turn, is proportional to the drive current
- A stepper motor usually has *2 phases;* more complicated designs with 3 and even 5 phases exist
- A *pole* can be defined as one of the regions where the magnetic flux density is concentrated; there are poles on both the rotor as well as on the stator
- Increasing the number of poles on rotor and/or stator leads to smaller basic stepping angles (full step)

Control of a stepper motor

- Example: *Unipolar* 2-phase stepper motor with one pair of poles per phase and one pair of rotor poles
- The flux can be reversed by switching the supply from phase A/B to phase $\underline{A}/\underline{B}$

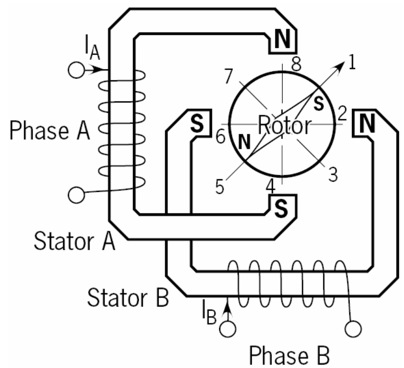






Control of a stepper motor

- Example: *Bipolar* 2-phase stepper motor with one pair of poles per phase and one pair of rotor poles
- The flux can be reversed by swapping the + and - terminals of the supply
- 8 full step positions are possible (basic step angle: 45°)



Control of a stepper motor

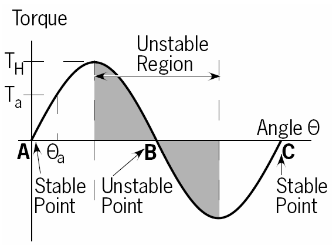
- The most common *stepping modes* are *wave drive*, *full step drive* and *half step drive*
- In a *wave drive* system only one phase is energized at any given time; sequence: A → B → $\underline{A}$ → $\underline{B}$ … leads to steps from 8 → 2 → 4 → 6 (see MP10-18)
- In a *full step drive* system two phases are energized at any time; sequence: AB → $\underline{A}$B → $\underline{AB}$ → A$\underline{B}$ … leads to steps from 1 → 3 → 5 → 7 (see MP10-18)
- A *half step drive* system combines the above two modes; sequence: AB → B → $\underline{A}$B → $\underline{A}$ → $\underline{AB}$ → $\underline{B}$ → A$\underline{B}$ → A … (1 → 2 → 3 → 4 → 5 → 6 → 7 → 8)

Control of a stepper motor

- The advantage of *full step drive* over *wave drive* is that, at any given time, a full step system uses 50% of the available windings whereas the equivalent wave drive system only uses 25%
- Furthermore, *unipolar stepper motors* only use 50% of each winding to build up the magnetic flux; *bi-polar stepper motors* on the other hand use the full winding and therefore produce more torque
- *Microstepping* systems continuously vary the current amplitude in the windings to break up a basic step into many smaller discrete steps

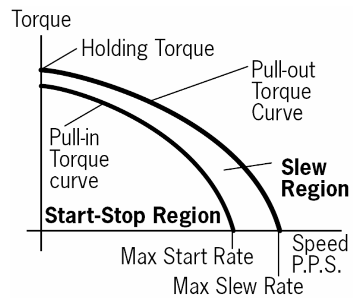
Control of a stepper motor

- The *stiffness* of a stepper motor can be increased by increasing its *holding torque* (T_H); moving the drive shaft away from an equilibrium position (rotor and stator poles are aligned) leads to an opposing torque which increases until T_H is reached
- Beyond the holding torque, the rotor position becomes unstable and it moves until it is aligned with the next stator pole



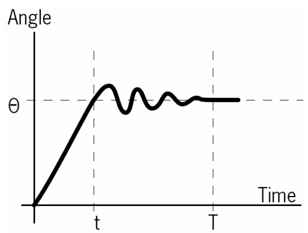
Control of a stepper motor

- The *torque vs. speed characteristic* of a stepper motor indicates its *pull-in curve* (defines a region at which the motor can be started/stopped without loss of synchronism)…
- … as well as its *pull-out curve* (limits the *slew region*, i. e. the region within which the motor can be operated without loss of synchronism)



Control of a stepper motor

- The time-domain response of a single step is subject to load conditions and the maximum required acceleration



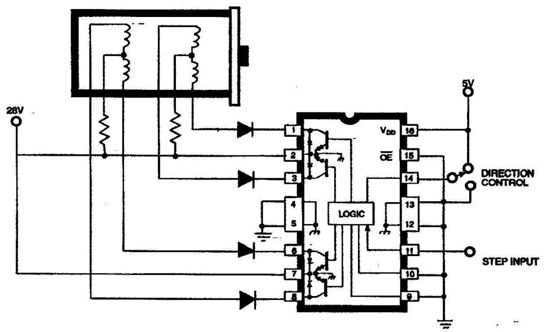
- Driving the motor at frequencies near the natural frequency of the rotor can lead to *resonance;* this resonance manifests itself in a sudden loss or drop in torque at certain speeds which can lead to loss of synchronism

Control of a stepper motor

- The *driver* of a stepper motor can be implemented using a microcontroller; the controller needs to produce the required pulse sequence and interface to an array of inverters or power MOSFETs
- This would only be done for educational purposes; in the ‘real world’ a *stepper motor driver chip* would be used (cost: ‘a few dollars’)
- This reduces the task to the provision of a pulse sequence, the frequency of which defines the rotational speed, and a directional signal (fw. / rev.)

Control of a stepper motor

- A typical design of a stepper motor driver is shown below; note that the transistors of the power amplifier often have to be implemented externally



Further reading:

[1]
Douglas W. Jones, *Control of Stepping Motors – A Tutorial,* http://www.cs.uiowa.edu/~jones/step/, accessed: January 2005

[2]
ELF/DWARF, *Free Standards Group – Reference Specifications,* www.linuxbase.org/spec/refspecs/, accessed: January 2005

[3]
The GCC Project, *Free Software Foundation,* gcc.gnu.org/, accessed: January 2005