2.7.21 Dynamic vehicle position sensors

These sensors are used for systems such as active suspension, stability control and general systems where the movement of the vehicle is involved. Most involve the basic principle of an accelerometer; that is, a ball hanging on a string or a seismic mass acting on a sensor.

2.7.22 Sensors: summary

The above brief look at various sensors hardly scratches the surface of the number of types, and the range of sensors available for specific tasks. The subject of instrumentation is now a science in its own right. The overall intention of this section has been to highlight some of the problems and solutions to the measurement of variables associated with vehicle technology.

Sensors used by motor vehicle systems are following a trend towards greater integration of processing power in the actual sensor. Four techniques are considered, starting with the conventional system. Figure 2.69 shows each level of sensor integration in a block diagram form.

Conventional

Analogue sensor in which the signal is transmitted to the ECU via a simple wire circuit. This technique is very susceptible to interference.

Integration level 1

Analogue signal processing is now added to the sensor, this improves the resistance to interference.

Integration level 2

At the second level of integration, analogue to-digital conversion is also included in the sensor. This signal is made bus compatible (CAN for example) and hence becomes interference proof.

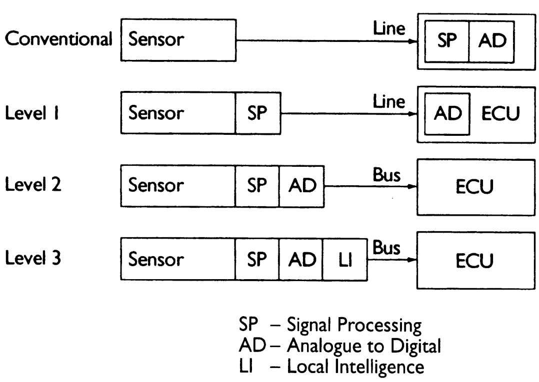

Figure 2.69 Block diagram of four types of sensors and their differing aspects

Integration level 3

The final level of integration is to include 'intelligence' in the form of a microcomputer as part of the sensor. The digital output will be interference proof. This level of integration will also allow built in monitoring and diagnostic ability. These types of sensor are very expensive at the time of writing but the price is falling and will continue to do so as more use is made of the 'intelligent sensor'.

2.7.23 Actuators: introduction

There are many ways of providing control over variables in and around the vehicle. 'Actuators' is a general term used here to describe a control mechanism. When controlled electrically actuators will work either by the thermal or magnetic effect. In this section, the term actuator will be used to mean a device that converts electrical signals into mechanical movement. This section is not written with the intention of describing all available types of actuator. Its intention is to describe some of the principles and techniques used in controlling a wide range of vehicle systems.

2.7.24 Solenoid actuators

The basic operation of solenoid actuators is very simple. The term 'solenoid' means: 'many coils of wire wound onto a hollow tube'. However, the term is often misused, but has become so entrenched that terms like 'starter solenoid' – when really it is starter relay – are in common use.

A good example of a solenoid actuator is a fuel injector. Figure 2.70 shows a typical example. When the windings are energized the armature is attracted due to magnetism and compresses the spring. In the case of a fuel injector, the movement is restricted to about 0.1 mm. The period that an injector remains open is very small – under various operating conditions, between 1.5 and 10 ms is typical. The time it takes an injector to open and close is also critical for accurate fuel metering. Further details about injection systems are discussed in Chapters 9 and 10.

The reaction time for a solenoid-operated device, such as a fuel injector, depends very much on the inductance of the winding. Figure 2.71 shows a graph of solenoid-operated actuator variables.

A suitable formula to show the relationship between some of the variables is as follows:

$$i = \frac{V}{R}(1 - e^{-Rt/L})$$

where i = instantaneous current in the winding, V = supply voltage, R = total circuit resistance, L = inductance of the injector winding, t = time current has been flowing, e = base of natural logs.

The resistance of commonly used injectors is about 16 Ω. Some systems use ballast resistors in series with the fuel injectors. This allows lower inductance and resistance operating windings to be used, thus speeding up reaction time. Other types of solenoid actuators, for example door lock actuators, have less critical reaction times. However, the basic principle remains the same.

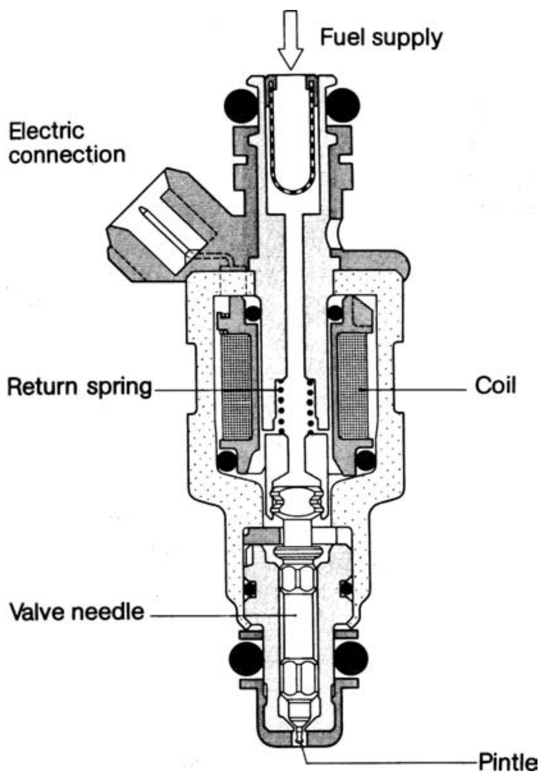

Figure 2.70 Fuel injector (MK 1)

2.7.25 Motorized actuators

Permanent magnet electric motors are used in many applications and are very versatile. The output of a motor is, of course, rotation, but this can be used in many ways. If the motor drives a rotating 'nut' through which a plunger is fitted, and on which there is a screw thread, the rotary action can easily be converted to linear movement. In most vehicle applications the output of the motor has to be geared down, this is to reduce speed and increase torque. Permanent magnet motors are almost universally used now in place of older and less practical motors with field windings. Some typical examples of where these motors are used are:

- windscreen wipers
- windscreen washers
- headlight lift
- electric windows
- electric sun roof
- electric aerial operation
- seat adjustment
- mirror adjustment
- headlight washers
- headlight wipers
- fuel pumps
- ventilation fans.

One disadvantage of simple motor actuators is that no direct feedback of position is possible. This is not required in many applications; however, in some cases, such as seat adjustment when a 'memory' of the position may be needed, a variable resistor type sensor can be fitted to provide feedback. A typical motor actuator is shown in Figure 2.72.

A rotary idle actuator is shown in Figure 2.73. This device is used to control idle speed by controlling air bypass. There are two basic types in common

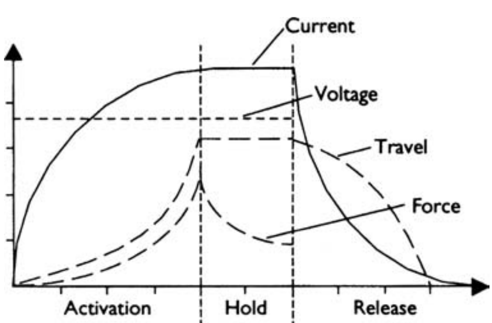

Figure 2.71 Solenoid-operated actuator variables

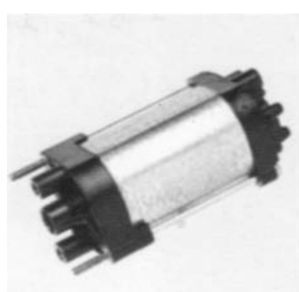

Figure 2.72 Seat adjustment motor

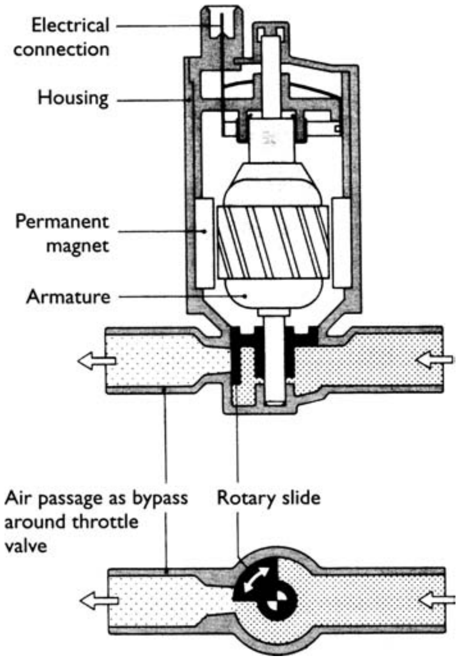

Figure 2.73 Rotary idle actuator

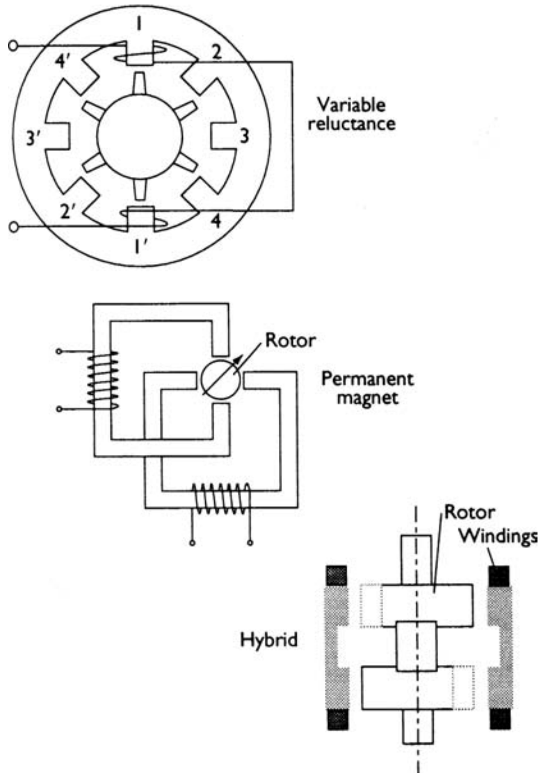

Figure 2.74 Basic principle of variable reluctance, permanent magnet and hybrid stepper motors

use. These are single winding types, which have two terminals, and double winding types, which have three terminals. Under ECU control, the motor is caused to open and close a shutter, thus controlling air bypass. These actuators only rotate about 90° to open and close the valve. As these are permanent magnet motors, the term 'single or double windings' refers to the armature.

The single winding type is fed with a square wave signal causing it to open against a spring and then close again, under spring tension. The on/off ratio or duty cycle of the square wave will determine the average valve open time and hence idle speed.

With the double winding type the same square wave signal is sent to one winding but the inverse signal is sent to the other. As the windings are wound in opposition to each other if the duty cycle is 50% then no movement will take place. Altering the ratio will now cause the shutter to move in one direction or the other.

2.7.26 Stepper motors

Stepper motors are becoming increasingly popular as actuators in motor vehicles and in many other applications. This is mainly because of the ease with which they can be controlled by electronic systems.

Stepper motors fall into three distinct groups:

1. variable reluctance motors
2. permanent magnet motors
3. hybrid motors.

Figure 2.74 shows the basic principle of variable reluctance, permanent magnet and hybrid stepper motors. The operation of each is described briefly but note that the underlying principle is the same for each type.

Variable reluctance motors rely on the physical principle of maximum flux. A number of windings are set in a circle on a toothed stator. The rotor also has teeth and is made of a permeable material. Note in this example that the rotor has two teeth less than the stator. When current is supplied to a pair of windings of one phase, the rotor will line up with its teeth positioned such as to achieve maximum flux. It is now simply a matter of energizing the windings in a suitable order to move the rotor. For example, if phase four is energized, the motor will 'step' once in a clockwise direction. If phase two is energized the step would be anti-clockwise.

These motors do not have a very high operating torque and have no torque in the non-excited state. They can, however, operate at relatively high frequencies. The step angles are usually 15°, 7.5°, 1.8° or 0.45°.

Permanent magnet stepper motors have a much higher starting torque and also have a holding torque when not energized. The rotor is now, in effect, a permanent magnet. In a *variable reluctance*

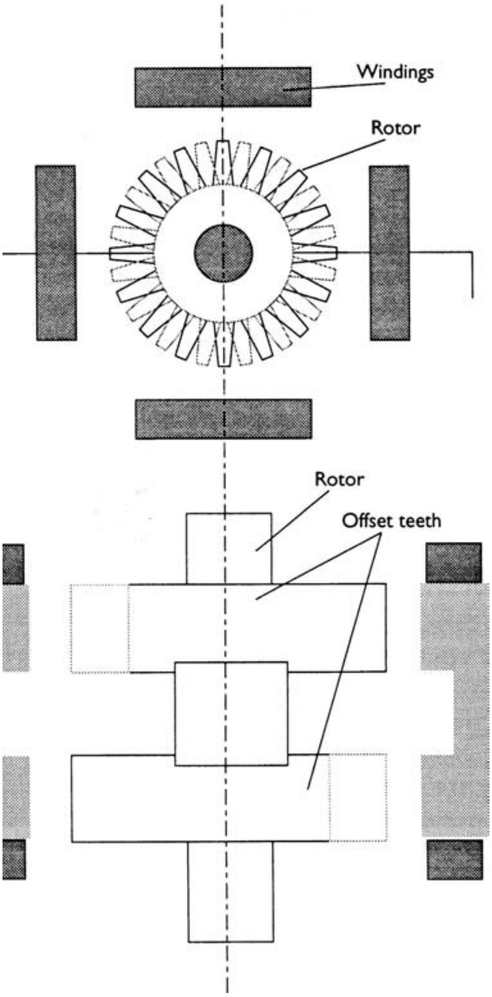

Figure 2.75 Stepper motor with double stators displaced by one pole pitch

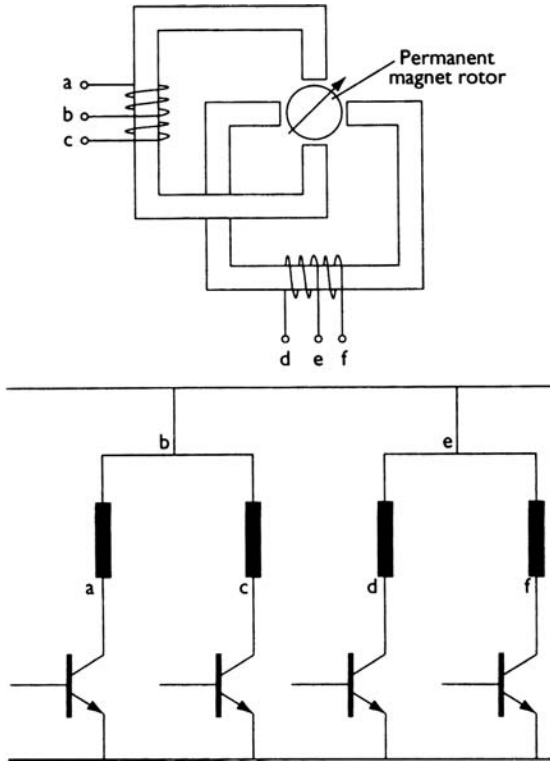

Figure 2.76 Four-phase stepper motor and circuit

motor the direction of current in the windings does not change; however, it is the change in direction of current that causes the *permanent magnet motor* to step. Permanent magnet stepper motors have step angles of 45°, 18°, 15° or 7.5°. Because of their better torque and holding properties, permanent magnet motors are becoming increasingly popular. For this reason, this type of motor will be explained in greater detail.

The hybrid stepper motor as shown in Figure 2.75 is, as the name suggests, a combination of the previous two motors. These motors were developed to try and combine the high speed operation and good resolution of the variable reluctance type with the better torque properties of the permanent magnet motor. A pair of toothed wheels is positioned on either side of the magnet. The teeth on the 'North' and 'South' wheels are offset such as to take advantage of the variable reluctance principle but without losing all the torque benefits. Step angles of these motors are very small: 1.8°, 0.75° or 0.36°.

All of the above-mentioned types of motor have been, and are being, used in various vehicle applications. These applications range from idle speed air bypass and carburettor choke control to speedometer display drivers.

Let us look now in more detail at the operation and construction of the permanent magnet stepper motor. The most basic design for this type of motor comprises two double stators displaced by one pole pitch. The rotor is often made of barium-ferrite in the form of a sintered annular magnet. As the windings shown in Figure 2.76 are energized first in one direction then the other, the motor will rotate in 90° steps. The step angle is simply 360° divided by the number of stator poles. Half steps can be achieved by switching off a winding before it is reversed. This will cause the rotor to line up with the remaining stator poles and implement a half step of 45°. The direction of rotation is determined by the order in which the windings are switched on, off or reversed. Figure 2.76 shows a four-phase stepper motor and circuit.

Impulse sequence graphs for two phase stepper motors are shown in Figure 2.77. The first graph is for full steps, and the second graph for implementing half steps.

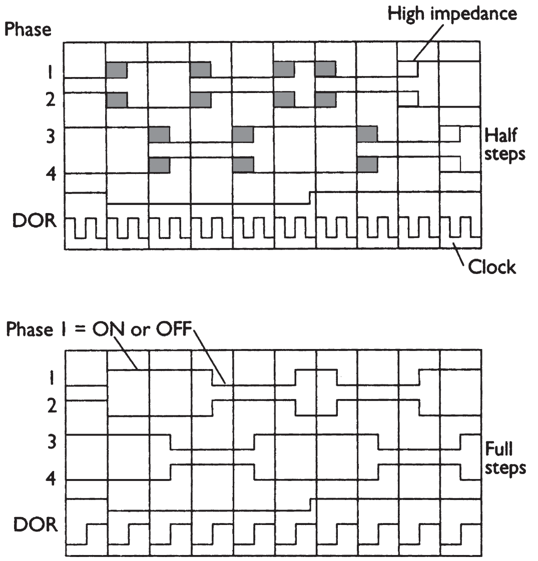

Figure 2.77 Impulse sequence graphs for two-phase stepper motors: the first graph is for half steps, the second for implementing full steps

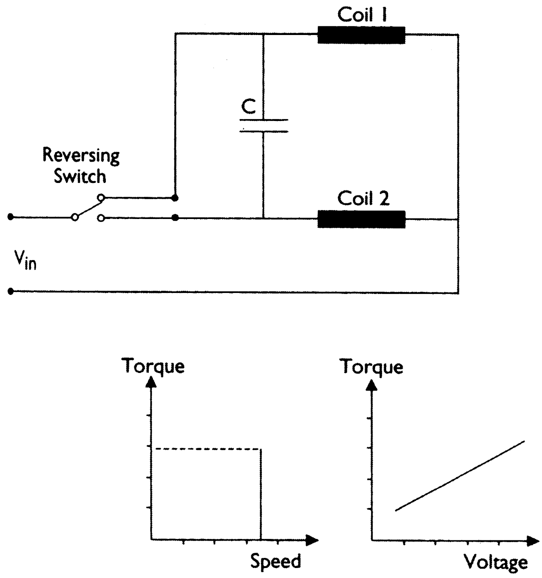

Figure 2.78 Reversing synchronous motor and circuit and its speed torque characteristic

The main advantage of a stepper motor is that feedback of position is not required. This is because the motor can be indexed to a known starting point and then a calculated number of steps will move the motor to any suitable position.

The calculations often required for stepper applications are listed below:

$\alpha = 360/z$
$z = 360/\alpha$
$f_z = (nz)/60$
$n = (f_z \times 60)/z$
$w = (f_z \times 2\pi)/z$

where α = step angle, n = revolutions per minute, w = angular velocity, f_z = step frequency, z = steps per revolution.

2.7.27 Synchronous motors

Synchronous motors are used when a drive is required that must be time synchronized. They always rotate at a constant speed, which is determined by the system frequency and the number of pole pairs in the motor.

$$n = (f \times 60)/p$$

where n = rpm; f = frequency; p = number of pole pairs.

Figure 2.78 shows a reversing synchronous motor and its circuit together with the speed torque characteristic. This shows a constant speed and a break off at maximum torque. Maximum torque is determined by supply voltage.

2.7.28 Thermal actuators

An example of a thermal actuator is the movement of a traditional-type fuel or temperature gauge needle (see Chapter 13). A further example is an auxiliary air device used on many earlier fuel injection systems. The principle of this device is shown in Figure 2.79. When current is supplied to the terminals, a heating element operates and causes a bimetallic strip to bend, which closes a simple valve.

The main advantage of this type of actuator, apart from its simplicity, is that if placed in a suitable position its reaction time will vary with the temperature of its surroundings. This is ideal for applications such as fast idle on cold starting control, where once the engine is hot no action is required from the actuator.

2.8 New developments

Development in electronics, particularly digital electronics, is so rapid that it is difficult to keep up. I have tried to provide a basic background in this chapter, because this is timeless. More systems are becoming 'computer'-based, and it is these digital aspects that are developing. The trend is towards greater integration and communication between systems. This allows for built-in fault diagnostics as well as monitoring of system performance to ensure compliance with legislation (particularly relating to emissions). The move towards greater on-board diagnostics (OBD) will continue.