# Control Systems

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## 1 Different types of systems

All our tools and machines need appropriate control to work, otherwise it will be difficult to finish their designated tasks accurately. Therefore, we need control systems to guide, instruct and regulate our tools and machines. Common control systems include mechanical, electronic, pneumatic and computer aided. A system usually contains three main parts: input, process and output.

### (a) Mechanical system

A mechanical system is a device made up of various mechanical parts. Its input is provided by an effort. Once the effort and is applied, it can set off a motion to move a load. The force applied to the load is the output of the mechanical system. Examples of mechanical systems include levers, gears and shafts. Fig. 1 shows some examples of mechanical systems.

(a) Can opener (b) Corkscrew

Fig. 1 Examples of mechanical systems

### (b) Electronic system

An electronic system is a system that employs electronic signals to control devices, such as radios, calculators, video game machines, mobile phones, portable computers, etc (Fig. 2). The input of an electronic system is provided by electronic signals. After they are processed, they can generate output signals, which control the operation of various devices, such as amplifiers and LCD. Electronic systems can carry out many different tasks, such as generating sound, transmitting information, displaying video, measuring, memorising, calculating, etc. Common examples of electronic devices include semi-conducting diode, transistors, capacitors that they are usually welded onto electronic circuit boards (Fig. 3).

(a) Mobile phone

(b) Portable computer

Fig. 2 Examples of electronic systems

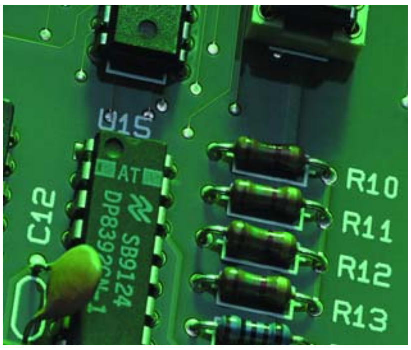



Fig. 3 Electronic circuit board

## (c) Computer control system

A computer control system uses a computer to control its output devices according to different input signals. Its function is similar to that of an electronic system. Yet a computer control system can use high speed calculation to process large volume of input signals within a very short time, and then generates appropriate outputs with the help of preset programs. Examples of computer control systems include computer numerical control press brakes, computer controlled home appliances, computer controlled underground railway systems, etc (Fig. 4).

(a) CNC press brake

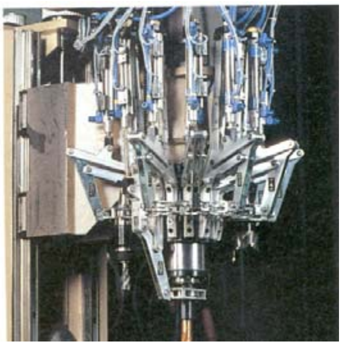
(b) A proposed computer controlled home appliances

Fig. 4 Examples of computer control systems

## (d) Pneumatic system

A pneumatic system is a system that uses compressed air to transport and control energy. Air is first pressurized to give energy in the cylinder. Then signals are input into the system through the use of switches. Next, air is transferred through sealed pipes to the pneumatic parts for processing. Finally, the force produced by the pneumatic parts is utilized to finish the designated task. The use of pneumatic systems is very extensive, for example, in controlling the movement of train doors, the operation of automatic production lines and mechanical clamps, etc (Fig. 5).

(a) Production line of CD-ROM



(b) Mechanical clamp

Fig. 5 Examples of pneumatic systems

## (e) Other systems

There exist many other control systems apart from the ones mentioned above, for example, mail processing systems, commercial operation systems, etc. The input, process and output of different systems have different properties. In this chapter, we will discuss some of the most common control systems.

# 2 Sub-systems

A system can be very simple, for example, a switch is only needed in controlling a light bulb to work. However, with the advancement of technology, most of the control systems gradually become complicated that various parts are involved. Take a lift as an example. It needs a number of parts to be cooperative in operation, so as to transport passengers to different storeys safely and rapidly (Fig. 6).

Fig. 6 (a) A sightseeing lift in a shopping arcade

(b) A lift in a hospital

A system may comprise some relatively small parts. They are known as sub-systems. For instance, a lift system includes driving system, door opening system, control system, safety system, lighting system, ventilation system and security system (Fig. 7). Fig. 8 shows a diagram to illustrate those sub-systems in a lift.

Fig. 7 (a) Control system (b) Driving system

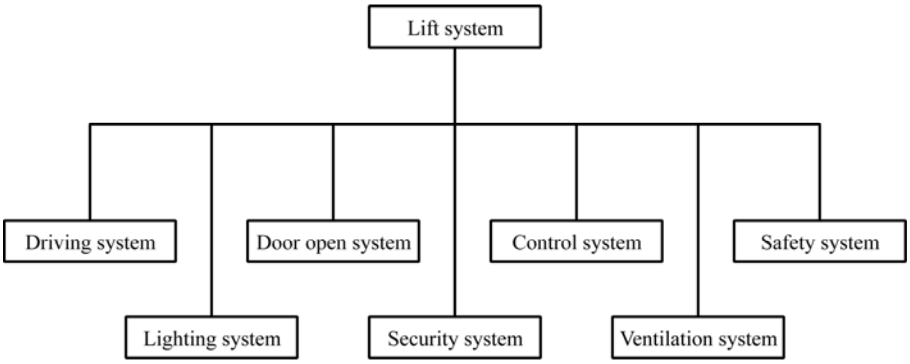



Fig. 8 Sub-systems in a lift

In fact, each sub-system can be considered as an independent system that includes input, process and output. While there exist relationships between the sub-systems that an output of one sub-system may become the input of another. Take the lift as an example. The output generated from the control system may affect the driving and door opening systems (Fig. 9). However, attention should be paid in the complexity of relationships of some sub-systems.

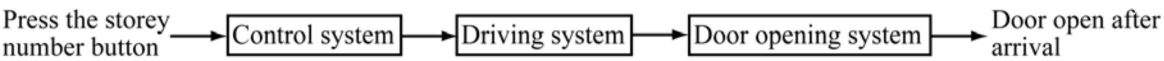



Fig. 9 Relationships between sub-systems

Therefore, when analyzing a complicated control system, that system can be divided into several comparatively simple sub-systems so as to familiar with the operation of the whole system easily. Besides, based on the sub-system concept, we could understand the relationships of the parts of the whole system much easier.

# 3 Different types of control systems

## (a) Open loop and closed loop control systems

There are basically two types of control system: the open loop system and the closed loop system. They can both be represented by block diagrams. A block diagram uses blocks to represent processes, while arrows are used to connect different input, process and output parts.

# (i) Open loop control system

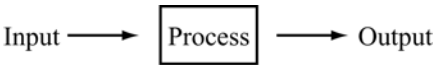



Fig. 10 Block diagram of an open loop control system

Fig. 10 shows a simple open loop control system. Its operation is very simple, when an input signal directs the control element to respond, an output will be produced. Examples of the open loop control systems include washing machines, light switches, gas ovens, etc.

(a) Washing machine (b) light switches

Fig. 11 Examples of open loop control system

A washing machine is an example of an open loop control system. Fig. 12 shows its block diagram. The input and output of an open loop system are unrelated. An example is that the operation of a washing machine does not depend on the cleanness of the clothes, but rather on the preset time. Both the structure and the control process of an open loop control system are very simple, but the result of the output depends on whether the input signal is appropriate or not.

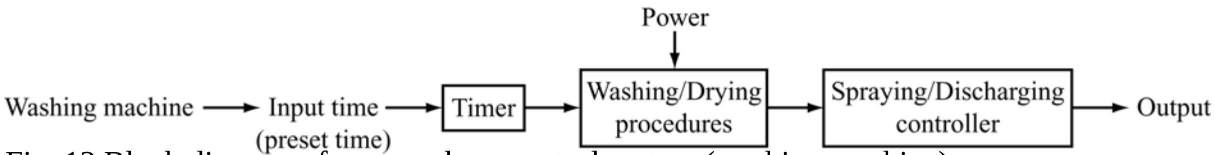



Fig. 12 Block diagram of an open loop control system (washing machine)

More sophisticated example of an open loop control system is the burglar alarm system (Fig. 13). The function of the sensor is to collect data regarding the concerned house. When the electronic sensor is triggered off (for example, by the entry of an unauthorized person), it will send a signal to the receiver. The receiver will then activate the alarm, which will in turn generate an alarm signal. The alarm signal will not cease until the alarm is stopped manually.

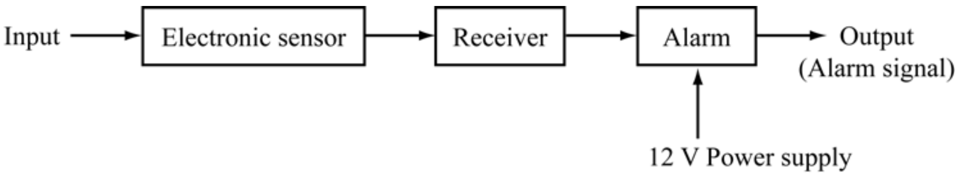



Fig. 13 Block diagram of an open loop control system (burglar alarm)

The drawback of an open loop control system is that it is incapable of making automatic adjustments. Even when the magnitude of the output is too big or too small, the system will not make the appropriate adjustments. For this reason, an open loop control system is not suitable for use as a complex control system. Sometimes it may even require monitoring and response from the user. For example, when a washing machine finishes cleaning the clothes, the user will need to check whether the clothes are clean or not; if they are not, they have to be put back into the machine and washed again.

## (ii) Closed loop control system

Sometimes, we may use the output of the control system to adjust the input signal. This is called feedback. Feedback is a special feature of a closed loop control system. A closed loop control system compares the output with the expected result or command status, then it takes appropriate control actions to adjust the input signal. Therefore, a closed loop system is always equipped with a sensor, which is used to monitor the output and compare it with the expected result. Fig. 14 shows a simple closed loop system. The output signal is fed back to the input to produce a new output. A well-designed feedback system can often increase the accuracy of the output.

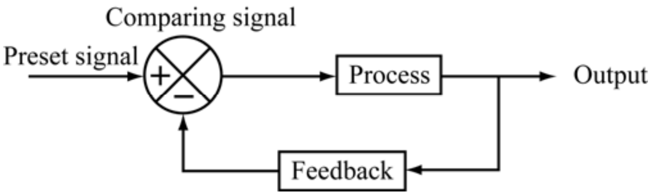



Fig. 14 Block diagram of a closed loop control system

Feedback can be divided into positive feedback and negative feedback. Positive feedback causes the new output to deviate from the present command status. For example, an amplifier is put next to a microphone, so the input volume will keep increasing, resulting in a very high output volume. Negative feedback directs the new output towards the present command status, so as to allow more sophisticated control. For example, a driver has to steer continuously to keep his car on the right track.

Most modern appliances and machinery are equipped with closed loop control systems. Examples include air conditioners, refrigerators, automatic rice cookers, automatic ticketing machines, etc. An air conditioner, for example, uses a thermostat to detect the temperature and control the operation of its electrical parts to keep the room temperature at a preset constant. Fig. 15 shows the block diagram of the control system of an air conditioner.

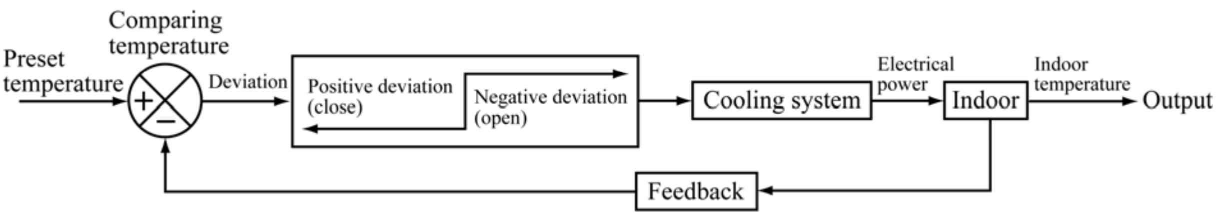



Fig. 15 Block diagram of the control system of an air conditioner

One advantage of using the closed loop control system is that it is able to adjust its output automatically by feeding the output signal back to the input. When the load changes, the error signals generated by the system will adjust the output. However, closed loop control systems are generally more complicated and thus more expensive to make.

# (b) Manual and automatic control systems

There were several stages in the history of development of technology. After the invention of steam engine and other machinery, the efficiency and the speed of production was improved in the era of Industrial Revolution. However, so many machines claimed to be automatic were those non-stop machines indeed. Owing to the lack of sensitive sensors and processors, those machines were not equipped with good control systems, thus they were only categorized as open loop control system.

To improve the precision of the control systems, operators were engaged to control the machines. They played an important role as sensors and decision-makers. They compared the inputs with the status needed, then provided feedback and made decision (their brains). Afterwards, they adopted some procedures to stabilize the systems and minimized the errors. Lastly, the outputs were close to the requirements. Therefore, manual operation in the system is a kind of closed loop control system.

After the trustable sensors, processors and driving devices were well developed, automatic machinery gradually replaced those manual ones. Under the conditions of clear and repeated procedures, and those procedures which are operated by automatic adjustment system instead, automatic control machinery is more suitable for use. Therefore, those automatic controlled machines are suitable for boring and repeated works. For example, it is better for a temperature sensor involved in the control of the switching on or off the compressor of the air conditioner.

After the emergence of processors and new models of sensors, manual control systems were gradually and easily replaced by computer control systems. Therefore, machinery becomes automatically controlled. For example, a newly developed "internet refrigerator" can automatically order food through internet when it is empty.

# (c) Applications of the control systems

There are many household and industrial application examples of the control systems, such as washing machine, air conditioner, security alarm system and automatic ticket selling machine, etc.

## (i) Washing machine

Nowadays, many families use fully automatic washing machines. There are numerous preset washing procedures available for the users. When we have chosen the suitable washing procedures, the machine automatically starts to pour water, add washing powder, spin and wash clothes, discharge wastewater, etc. After the completion of all the procedures, the washing machine will stop the operation.

Fully automatic washing machine only requires the user to input a suitable procedure to complete the whole washing process, thus this saves much time for the users. However, this kind of machine only operates according to the preset time to complete the whole washing process. It ignores the cleanness of the clothes and does not generate feedback. Therefore, this kind of washing machine is of open loop control system indeed, and their block diagram of control system of the washing machine as shown in Fig. 16.

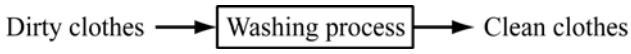



Fig. 16 Block diagram of the open loop control system of the washing machine

## (ii) Air conditioner

Nowadays, there are many families using automatic control system for the temperature of the air conditioner. Fig. 17 shows the interior structure of an air conditioner. The coolant circulated in the machine will absorb heat indoor, then it will be transported from the vaporization device to cooling device. The hot air is then blown to outdoor by a fan. There is an adjustable temperature device equipped in the air conditioner for the users to adjust the extent of cooling. When the temperature of the cool air is lower than the preset one, the controller of the air conditioner will stop the operation of the compressor to cease the circulation of the coolant. The temperature sensor installed near the vaporization device will continuously measure the indoor temperature, and send the results to the controller for further processing.

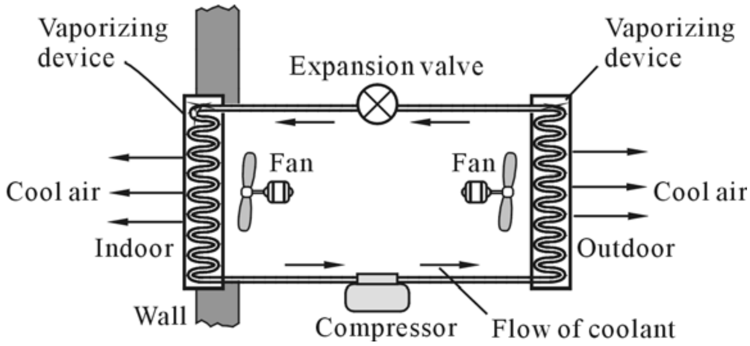



Fig. 17 Internal structure of an air conditioner

Since the output of cool air by the air conditioner will affect its working, thus the control system of the machine is a closed loop. Its block diagram of the control system is as shown in Fig. 18.

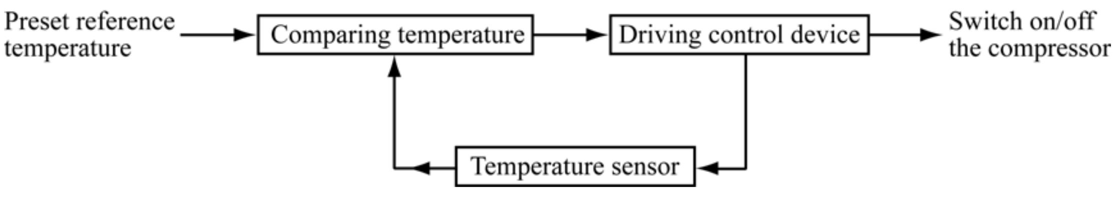



Fig. 18 Block diagram of the closed loop control system of the washing machine

# 4 Simple systems analysis

To analyse a simple control system, we must first understand its operation, and the control procedure of each part.

## (a) Operation block diagram

The operation of a control system may consist of many steps. For example, the operation of a washing machine can be represented by the following text:

1. Dirty clothes and an appropriate amount of detergent are put into the washing drum before the machine is turned on.
2. The washing drum is filled with water.
3. If the water temperature deviates from the preset value, more hot water will be added.
4. The internal program causes the washing drum to rotate, so the detergent and water inside can remove the dirt on the clothes.
5. The drum rotates at high speed controlled by the machine, so as to drain the excess water and dry the clothes.
6. Finally, the machine stops.

As it would take much time to explain the process in words, in order to save time, we can use an operation block diagram instead. Fig. 19 shows the operation block diagram of a washing machine. It is hoped that the diagram can help you understand quickly the sequence and relation of the main operational steps.

BLOCK DIAGRAM

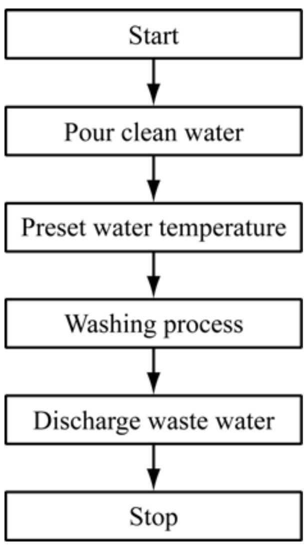



Fig. 19 Operation block diagram

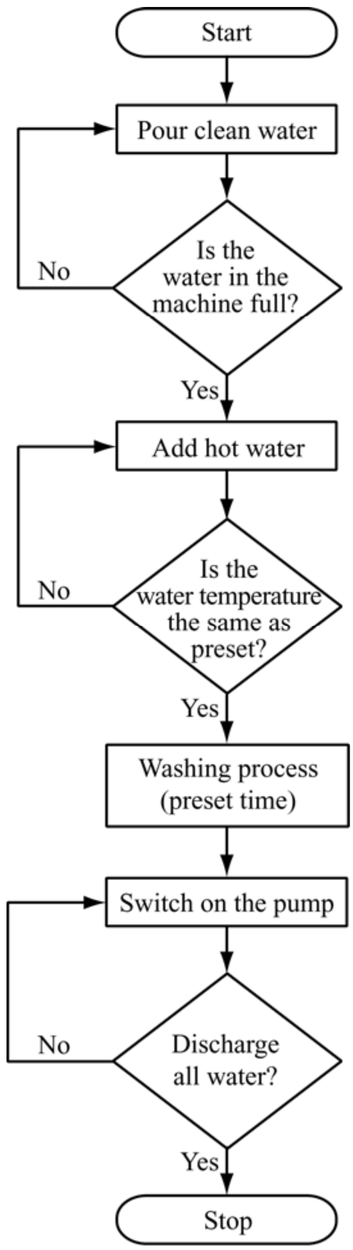



Fig. 20 Sequential control block diagram

# (b) Sequential control block diagram

Although an operation block diagram can show clearly the operation of a control system, it cannot show the decisive relations between the main controlling steps. For example, which step requires a sensor? In order to show more clearly the decisive relations between controlling steps, we can use a sequential control block diagram. Sequential control means to carry out the controlling steps sequentially following a preset order. Fig. 20 shows the sequential control block diagram of a washing machine. It shows clearly that a washing machine should have at least three sensors and feedback for filling the drum with water, testing the water temperature and draining of the drum, respectively.

# 5 Simple systems design

In designing a control system, one should consider factors such as its modes of input, process and output. Sometimes, a single control system may contain a number of systems, such as electrical driving systems, electronic control systems, mechanical systems, computer control programs, etc. They are all known as sub-systems. Before designing the system, one must first study the relations between each sub-system and how they can be coordinated.

For example, when designing an electric toothbrush, one should study its functions and properties to determine factors such as input, process and output. Apparently, an electric toothbrush should consist of two sub-systems: an electronic control system and a mechanical system. The relations between the factors can be represented using two operation block diagrams, as shown in Fig. 21 and Fig. 22.

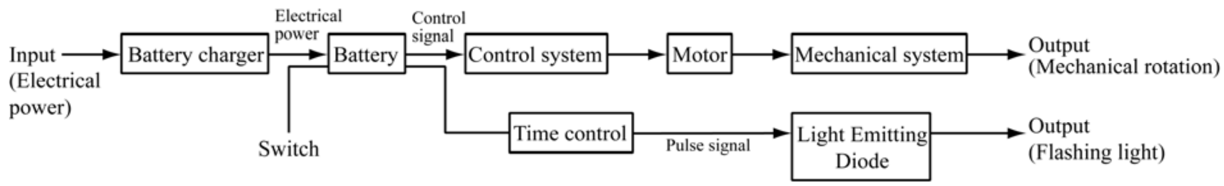



Fig. 21 Block diagram of an electronic control system

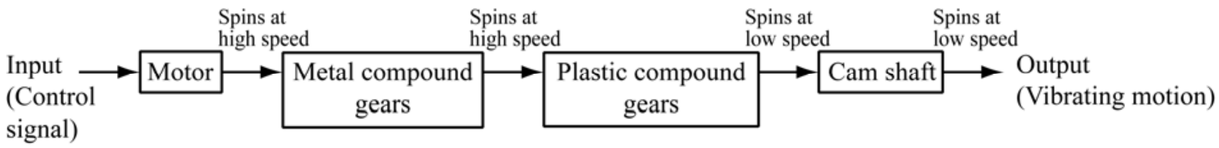



Fig. 22 Block diagram of a mechanical system

The structure of the electric toothbrush can be designed according to its operation block diagram. Fig. 23 shows the cross section of a typical electric toothbrush, the operation of which should correspond with the block diagrams shown above.

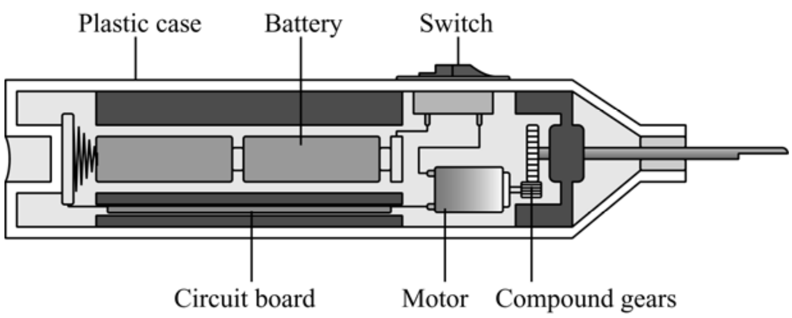



Fig. 23 Cross section of an electric toothbrush

# Exercise

1. Which three parts are commonly involved in a control system? How to categorize this control system?

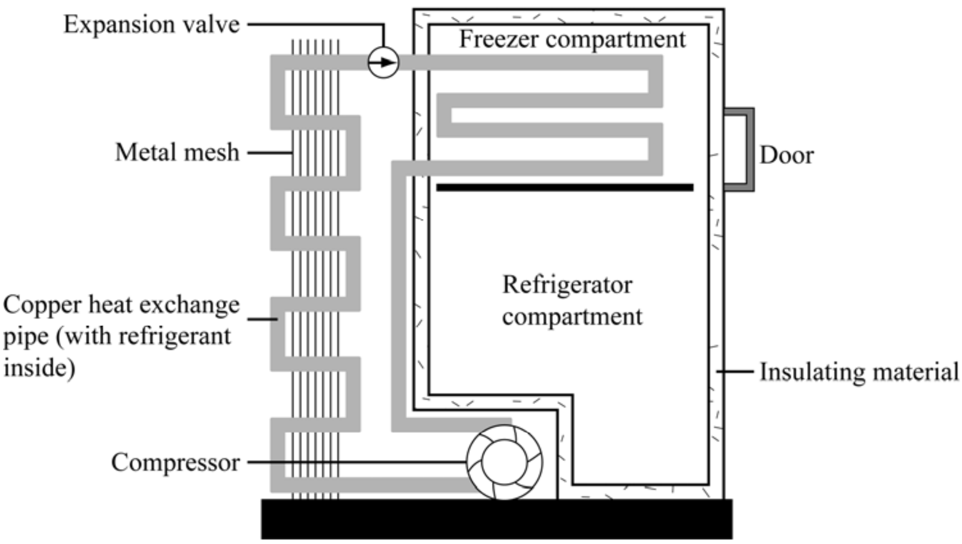
2. State the differences between a mechanical system and a pneumatic system.

3. What is the main difference between an open loop control system and a closed control system? Use block diagram to elaborate.

4. Explain the positive and negative feedback in a closed loop control system. What are the differences between them and how they affect the control system?

5. Draw the control block diagram for a household constant-temperature type (with double metallic sheets) electric iron.

6. The following diagram shows the structure of a refrigerator.




(a) Briefly describe the working principles of using refrigerant to absorb the heat in the refrigerator.

(b) Draw the block diagram of the cooling system of the refrigerator, and clearly mark the flow of the refrigerant.

(c) There is a temperature controller for the adjustment of the inner temperature of the refrigerator.

(i) Draw the block diagram of the control system of the refrigerator.

(ii) Is the control system of the refrigerator classified as open loop or close loop control system?