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Laboratory of Combustion Engines Theory

<u>Lab work № 5</u>

STUDY ON AUTOMOBILE AIR CONDITIONING SYSTEM

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Introduction

Air-conditioning (A/C) systems are very popular nowadays in passenger cars, and it is very likely that, due to climate changes it will be standard car equipment very soon. It is quite normal that some equipment that was a sign of luxury few years ago, become common thing today. Some car manufacturers say that A/C is also a system of safety. They use to ask a question: “Is it possible for the driver to act normally while the temperature in car interior exceeds 30 ˚C ? Are his reactions still fast enough ?"

Aim of the exercise:

To know Basic theory of refrigeration cycle and refrigerant features.
To make some basic measurements of how the real system works.
To make some diagnostic & troubleshooting conclusions.

The laboratory stand (intro)

In the laboratory stand there is a full set of A/C from commercial TOYOTA COROLLA (series 100). The system is installed on metal frame together with AC motor which plays the same role as an engine in the car. So, all components of the climate system correspond to that one of real car. Control unit is also taken from commercial car.

This system also uses the number of components that were omitted later, mainly for cost reasons, so developed stand and system is more complicated as we may find in the car.

The car A/C system, called “electronic”, use separate equipment to mix cold and warm air and system of electrically driven duct throttles to keep the temperature on the targeted level.

Theory – car cooler principle

EXPANSION AND EVAPORATION

In the mechanical refrigeration system, the cooled air is prepared by the following method. The high temperature and high pressure liquid refrigerant is stored in the container which is called a receiver. Then, the liquid refrigerant is released to the evaporator through a small hole, called the expansion valve. At this time, the temperature and pressure of the liquid refrigerant is lowered too, and some of the liquid refrigerant changes to vapour.
The low temperature and low pressure refrigerant flows into the container, called the evaporator. In the evaporator, the liquid refrigerant evaporates and removes heat from the surrounding air. The functional diagram of described system is shown on Fig. 1.

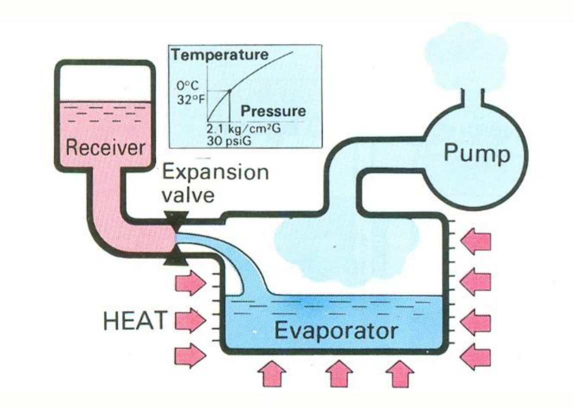

Fig.1. The functional diagram for mechanical refrigeration system

HOW TO CONDENSE GASEOUS R-12 INTO LIQUID

The system cannot make the cooled air when the liquid refrigerant is used up. So, new liquid refrigerant must be supplyed to the receiver. The mechanical refrigerant system changes the gaseous refrigerant which leaves the evaporator into liquid.

It is known, that when gas is compressed, both the temperature and pressure increase. For example, when gaseous refrigerant is compressed from 2.1 kg/cm^2 to 15 kg/cm^2, the temperature of the gaseous refrigerant increases from 0°C to 70°C (Fig.2). The boiling point of refrigerant at 15 kg/cm^2 is 62°C. So the temperature (70°C) of compressed gaseous refrigerant is higher than the boiling point (62°C) and also higher than the surrounding air. Therefore, this gaseous refrigerant can be converted into liquid by giving the heat off to the boiling point. For example, 1 5 kg/cm^2, 70°C gaseous refrigerant can be liquefied by lowering the temperature by about 8°C.

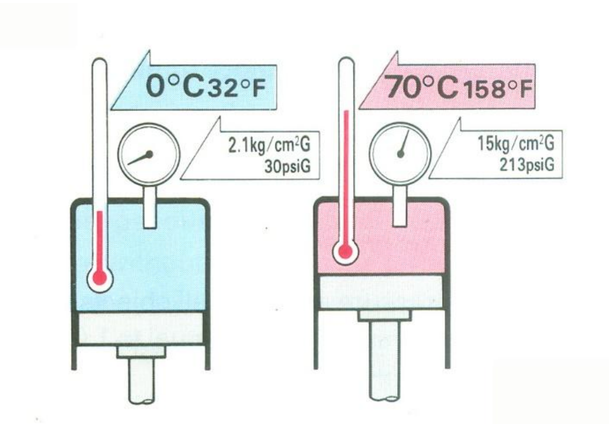

Fig.2. Processes of condense gas into liquis

CONDENSING THE GASEOUS R-12

In the mechanical refrigeration system, the liquefaction of the refrigerant is achieved by raising the pressure and then by lowering the temperature. The gaseous refrigerant which leaves the evaporator is compressed by the compressor. In the condenser the compressed gaseous refrigerant releases heat to the surrounding air and it condenses back into liquid. And then the liquid refrigerant returns to the receiver (Fig.3).

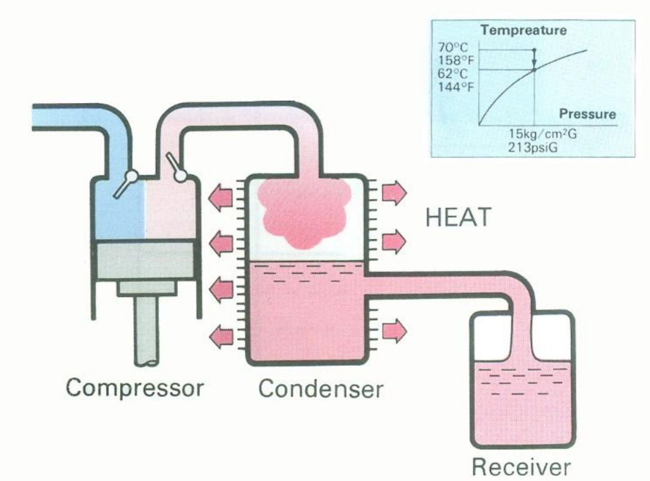

Fig.3. Process of condensing R12 refrigerant

Theory – RIFRIGERANT

To make a refrigeration cycle efficient, we need a special medium in the system. This medium we call refrigerant and it has some special features.

In car we use several different refrigerants.

The most popular refrigerant by the end of XX century was - CFC12 – chemical formula CCl_2F_2 , trade name R12.

As it was proved that chlorine (Cl) consisted in R12 is harmful to ozone layer it was changed to refrigerant not consisting chlorine -HCF134a - chemical formula CH_2 FCF_3 known as R134a

The old refrigerant (R12) was suppressed in new installations after a year 2000.

To replace R12 by R134a was reasonable for car systems, due to very high risk of releasing some amount of harmful refrigerant in the moment of front collision.
It is not so obvious for home installation as well as for our laboratory stand because we are taking care about the stand and as we always stay indoor, the risk of the road collision is not too high. The same concerns home installations.
That's why we still use old refrigerant in our stand. Simply retrofitting an old system with a new refrigerant is not possible, because of risk of damage the system seals.

Both refrigerants use trade name FREON.

CHARACTERISTICS OF R-12

Water boils at 100°C under atmospheric pressure, but R-12 boils at -29.8°C under atmospheric pressure. Water boils at 121 °C under 1 kg/cm^{2}G of pressure, but R-12 boils at -13°C under 1 kg/cm^{2}G of pressure as it shown on Fig. 4.
If R-12 were exposed and released to the air under normal room temperature and atmospheric pressure, it would absorb the heat from the surrounding air and boil

immediately, changing into gas. Also R-12 easily condenses back into liquid under pressurized conditions while removing the heat from it.
The graph on Fig.5 shows the characteristic of R-12 which expresses the relation between the temperature and pressure. The graph indicates the BOILING POINT OF R-12 under each temperature and pressure. On the graph, the upper portion above the curve is R-12 in a gaseous state and the lower portion below the curve is R-12 in a liquid state. The gaseous refrigerant can be converted into the liquid refrigerant by raising the pressure without changing the temperature or decreasing the temperature without changing the pressure.

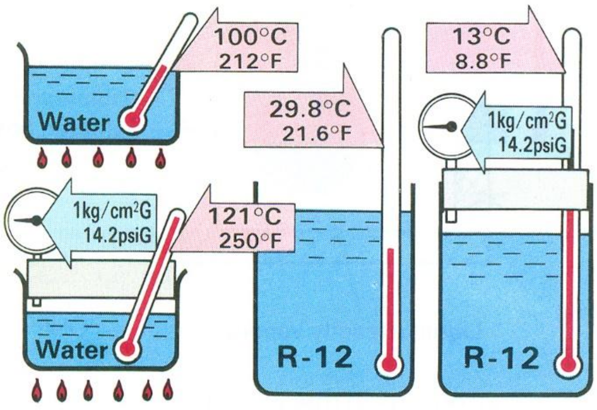

Fig.4. Boiling characteristics for R12

Conversely, the liquid refrigerant can be converted into the gaseous refrigerant by lowering the pressure without changing the temperature, or by raising the temperature without changing the pressure.
This refrigerant (R-12) is one of the safest gases for the coolers. It is non-flammable, non-explosive, non-poisonous, non-corrosive, odourless and harmless to clothes and food.

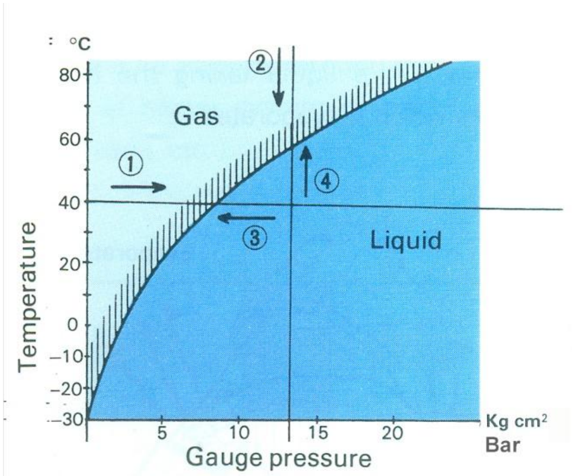

Fig.5. Properties of the refrigerant R12

Theory – car cooler principle

The basics of refrigeration cycle can be found in the course of Thermodynamics. The aim of present study is to find out the difference between engine cycle and cooler cycle.

In Engine cycle there are:

On input:

1. Warming Heat
2. Compression

And output of

1. Expansion
2. Cooling Heat

This cycle runs clockwise

In refrigeration cycle there are:

On input:

3. Evaporation Heat
4. Compression

And output of

3. Expansion
4. Condensation Heat

This cycle runs anticlockwise.

CAR A/C System

The design of automobile air conditioning system is shown on Fig. 6

BASICS OF REFRIGERATION CYCLE

1. The compressor discharges high temperature and high pressure refrigerant that contains the heat absorbed from the evaporator plus the heat created by the compressor in a discharge stroke.
2. This gaseous refrigerant flows into the condenser. In the condenser, through heat transfer process, the gaseous refrigerant condenses into liquid refrigerant.
3. This liquid refrigerant flows into the receiver which stores, filters and dehydrates until the evaporator requires the refrigerant.
4. The expansion valve changes the liquid refrigerant into mixture of liquid and gas with low temperature and low pressure.
5. This cold and foggy refrigerant flows to the evaporator.
6. During vaporizing of the liquid in the evaporator, the heat from the warm air stream passing through the evaporator core and is transferred to the refrigerant. In such conditions all the liquid will change into the gaseous refrigerant in the

evaporator and only heat-laden gaseous refrigerant goes into the compressor. Then the process is repeated again.

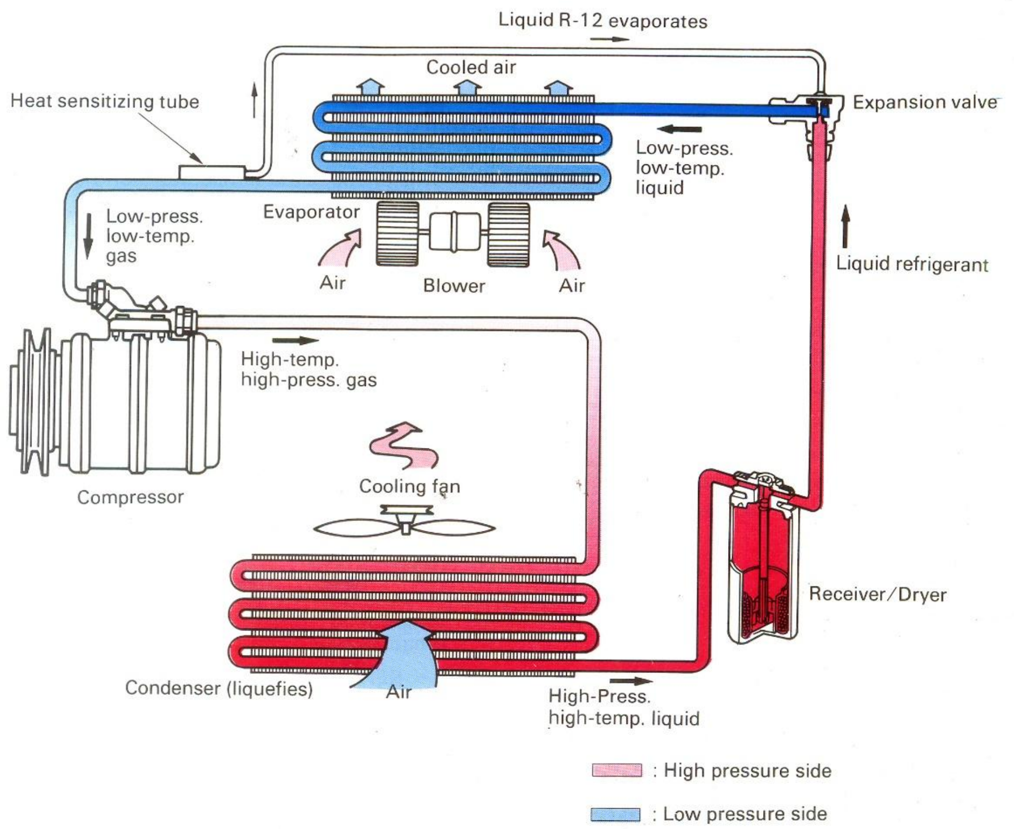

Fig.6. Design of the automobile air conditioning system

A/C System components

1-Compressor

There are three types of compressor, that are used in car A/C systems

The type used in our stand is a vane type that is shown on Fig.7.

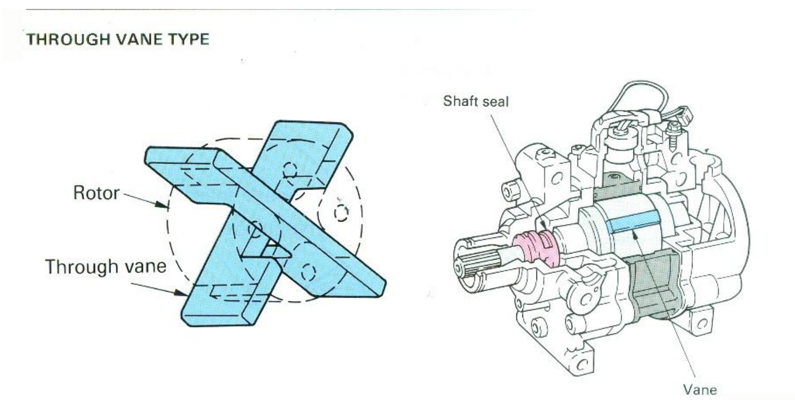

Fig.7. Design of vanes

Consequence of working strokes in A/C compressor are shown on Fig.8.

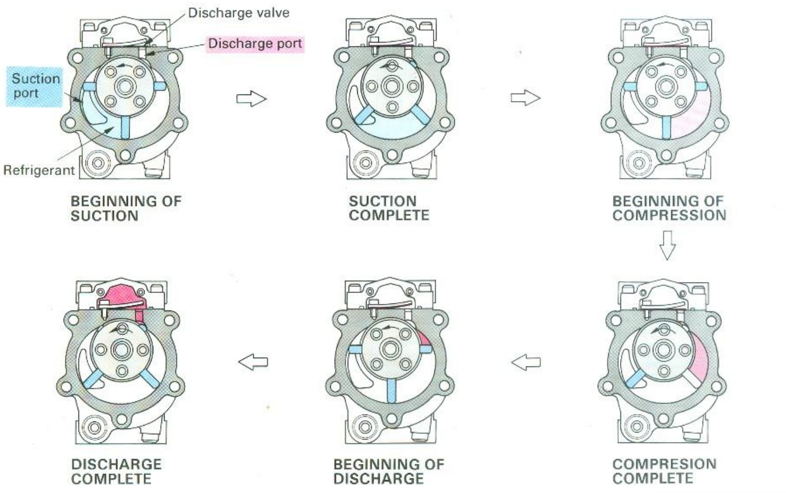

Fig.8 Principle of work of vane-type compressor

The most popular nowadays in car A/C systems is a swash plate type compressor (Fig.9)

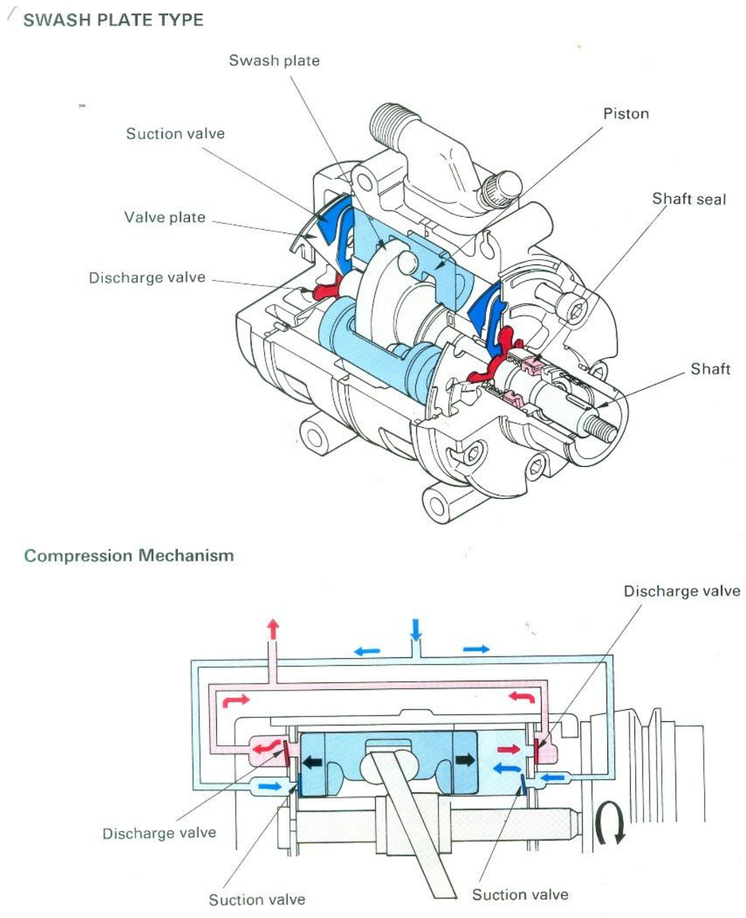

Fig.9. Swash plate type compressor

The third type is a crank type (Fig.10), used in most of home refrigerators.

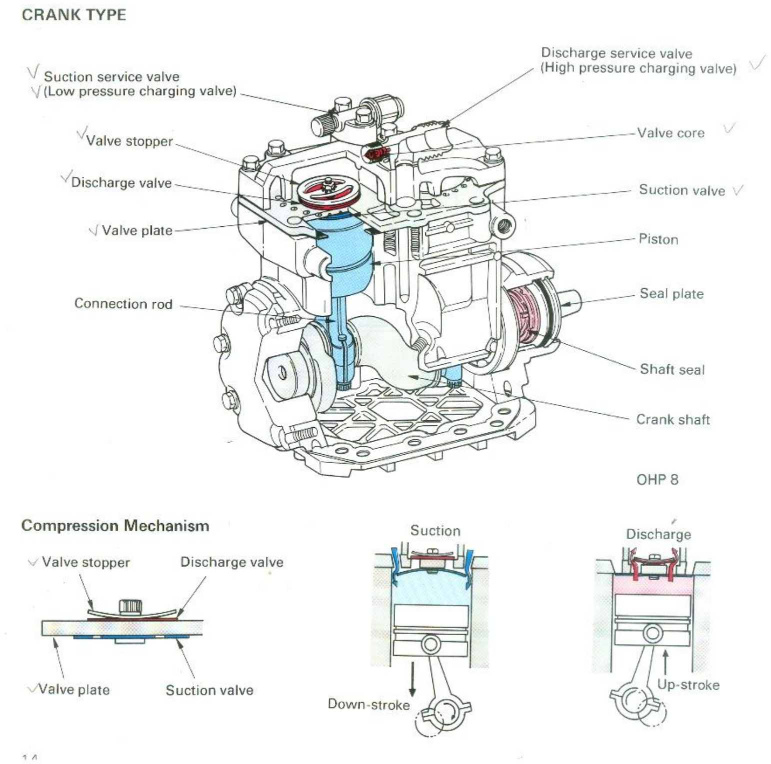

Fig.10 Crank type compressor

2- Condenser

Condenser look more or less like engine cooler and is usually placed beside it.
In other words, A/C condenser as well as engine cooler are placed parallel, however they have separate cooling fans to allow A/C work correctly when car is parked.
In condenser, the heat taken out from cars interior and given to the refrigerant in compression process is transferred to the ambient air. The higher condenser capacity the bigger amount of heat taken from car interior is possible.

3- Receiver-dryer

As refrigerant is hygroscopic, so the function of receiver-dryer is to separate water from the system as well as storing excess of refrigerant while expansion valve is „closed".

If water is present in the refrigerant, it will freeze and simply block the system. As the result, the system efficiency will drastically drop. The dryer has limited capacity, so it can absorb only some amount of water and after that it simply stop working. It means that if the system was for some reasons opened for a longer time the dryer should always be replaced with the new one during system repair and refrigerant retrofitting.

Additionally it has looking glass eye to monitor state of refrigerant it has also a fusible unit that in case of pressure increase above more or less 3 MPa or temperature increase above 95 °C allows refrigerant to be released out of the A/C system.

4-Evaporator

Evaporator together with fan taking air into the cars interior work as a cooling unit. Evaporator (Fig.11) looks almost the same as heater and it is placed in the main air duct together with heater.

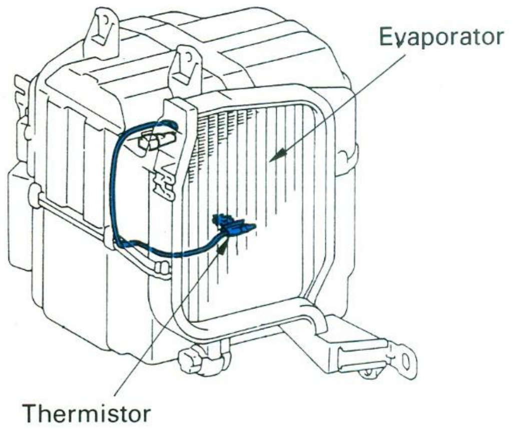

Fig.11. Evaporator with thermistor

5-Expansion valve

Expansion valve is used to decrease refrigerant pressure and convert it into the moist vapour. To achieve full A/C efficiency, the whole refrigerant should be evaporated in expansion valve. The pressure beyond the expansion valve is controlled by the heat sensor. Heat sensor gives information in the form of changing pressure that acts on valve membrane.

Design of expansion valve is presented on Fig. 12.

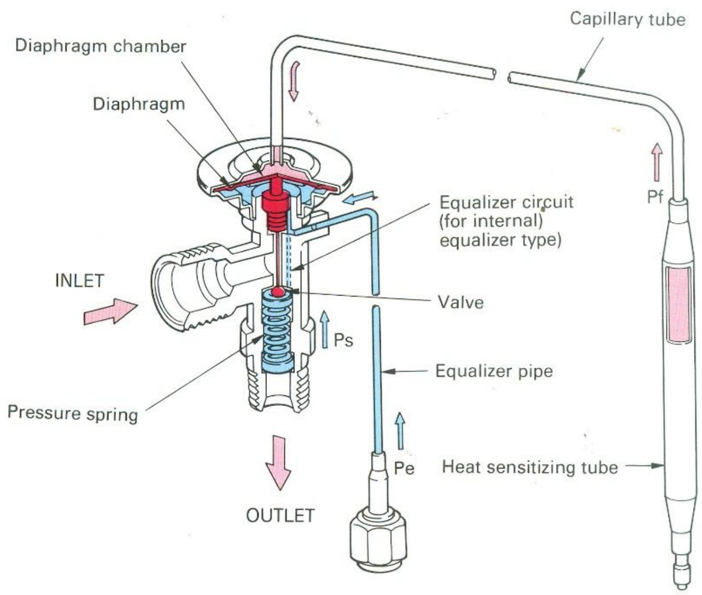

Fig. 12. Expansion valve

6-Control unit

Control unit for car A/C systems in Toyota cars is (traditionally) called amplifier.

It works using the following signals:

-Information abort air temperature measured in air duct on evaporator output. For measuring the temperature, the NTC thermistor sensor is used. Characteristic of thermistor sensor is shown on Fig.13.

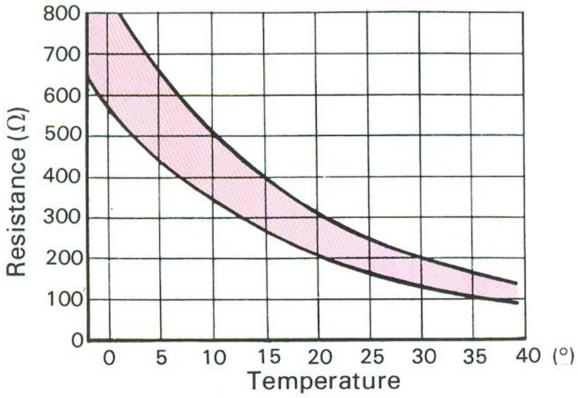

Fig.13. Characteristic of the thermistor sensor

-Information from the regulator placed on dashboard (if there is any). This is usually potentiometer that is “shifting” thermistor signal, depending on driver’s demands.

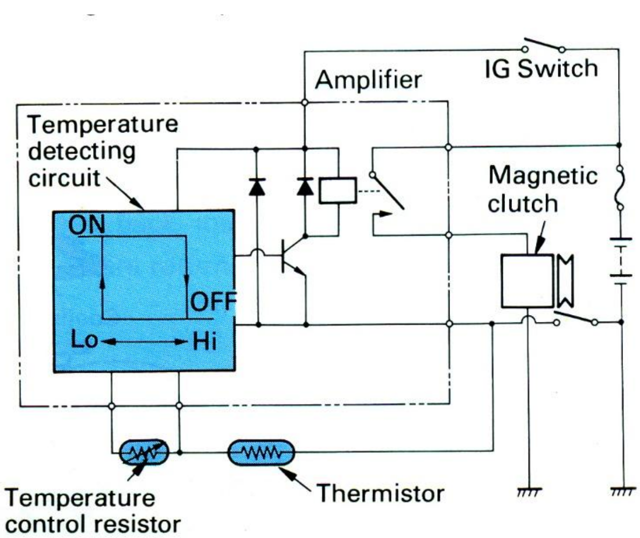

Fig. 14 Layout of the control unit

-According to the temperature measured by the thermistor, the control unit switches the compressor on or of using magnetic clutch.

7- Other A/C components

- Pressure switch

According to it’s signal, the compressor is switched off in case of pressure increase above the maximum value (2,7 MPa) and is switched on when pressure drops below the minimum value (0,21 MPa). Pressure switch is a membrane type.

- Anti-ice device

This device reduces evaporator icing, which decreases cooling efficiency of the A/C system.

- Idle-up device.

This device keeps engine running on idle speed when A/C is switched on, which considerably increases engine load. In such case „normal” engine idle speed is too low to keep the engine running. It is used in older cars, that are not equipped with engine management system. Location of the idle-up device is shown on Fig. 15.

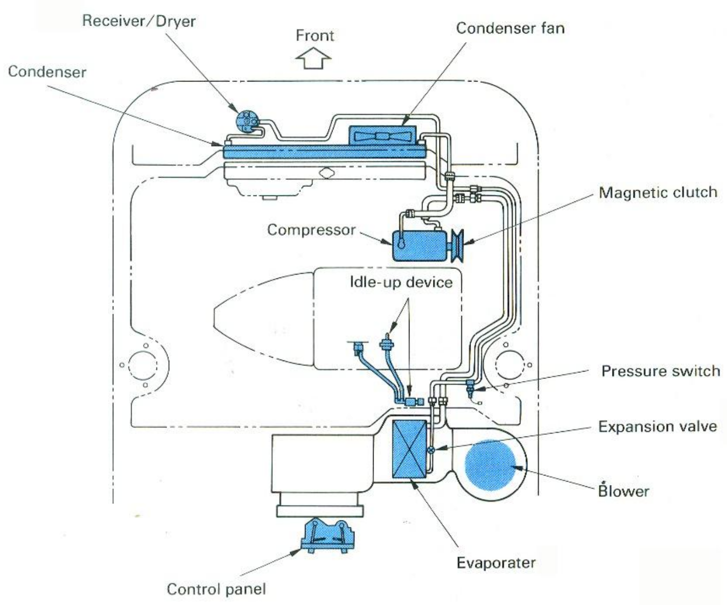

Fig. 15. Location of the different elements of A/C system under the hood

LABORATORY STAND

A/C system taken out of Toyota Corolla series 90 is placed on a special frame. The stand was built by students using factory A/C for retrofitting in dealers network.
Main components of the stand are presented on Fig. 16.

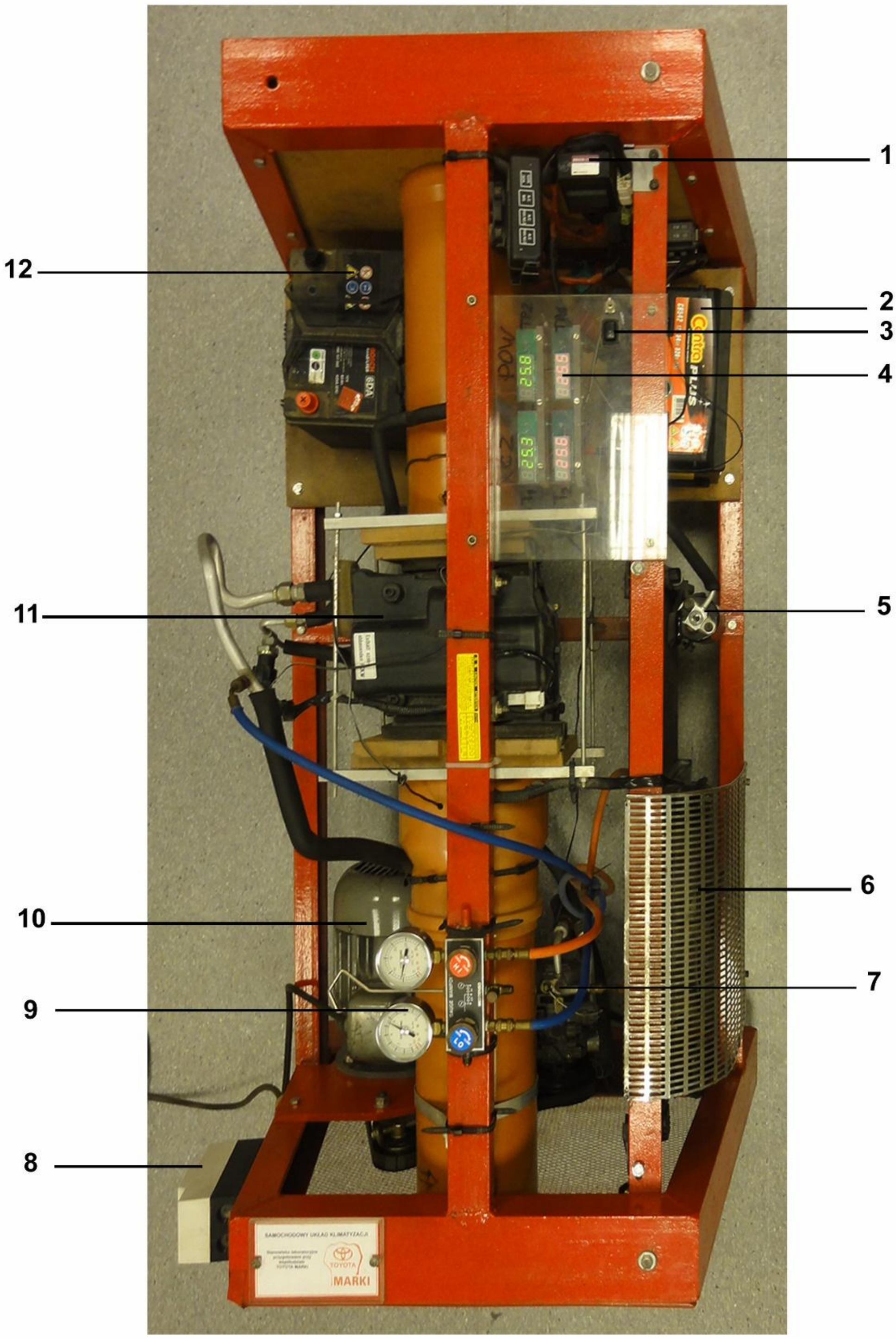

Fig.16. Laboratory stand

Main components of the stand are:

1 - A/C control unit (amplifier),

2 – Battery,

3 - A/C on/off switch,

4 - Temperature gauges unit,

5 - Receiver / dryer,

6 - Condenser with cover,

7 – Compressor,

8 - Electric motor switch,

9 - Three-way pressure gauge,

10 - 3-phase AC motor,

11 -Evaporator and expansion valve unit,

12 - Spare battery.

Laboratory stand details

The measuring equipment consist of:

- Four electronic temperature gauges.
- Three-way manometer connected to the diagnostic terminals on low/high pressure sides.

Starting the laboratory stand

To start the stand :

1-Connect the A/C motor to a 3-phase socket,
2-Connect the battery,
3-Turn on the 12V cut-off switch on the side of the stand (cat-off switch is shown on Fig.17),

Fig.17. The 12V cut-off switch on the side of the stand

This procedure is almost the same as drivers behaviour and follows the same rules, as putting in the ignition key and turning it to ACC position.
After that, one can hear the sound of “heater” fan that is placed by the 12V cut-off switch.

4. Switch the A/C motor ON
The switch panel is shown on Fig. 18

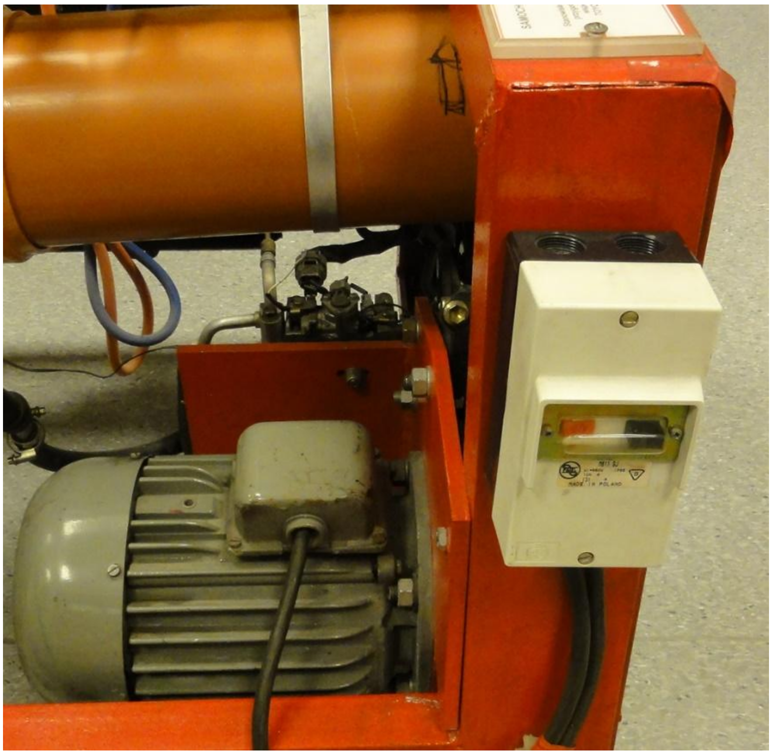

Fig.18. Switch panel for A/C motor

Press on the black key, motor should start working – that is the same as driver will experience by turning the ignitron key into the start position.

5. Turn the A/C switch on.

After a few seconds the changes on temperature gauges will appear (Fig. 19).

Fig.19. Panel of the stand with temperature gage and A/C switcher

7. The actual pressure is to be controlled on pressure gauges shown on Fig. 20

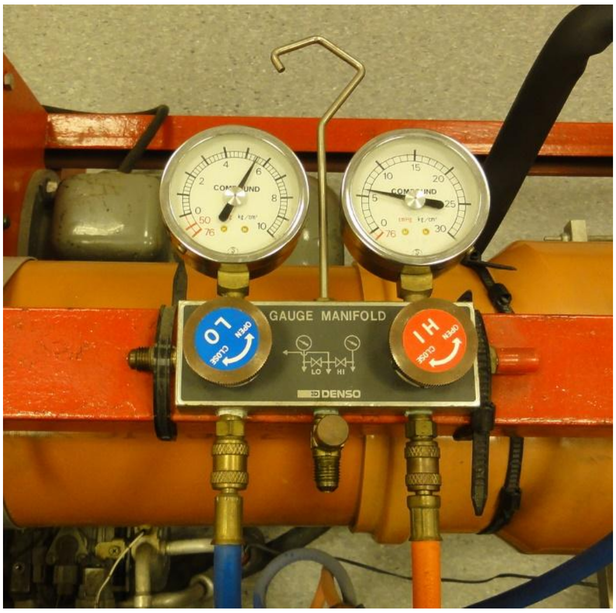

Fig.20. Pressure gauges.

The highest pressure values should be about 1,5 MPa, typically about 1,1 MPa

Switching off the stand is carried out in reverse order.

Measurements:

Pressure
- on a high pressure side (red) – p2
- on a low pressure side (blue) – p1

Time:
On-off timing for the compressor, starting from the first switching it on.
Time is to be measured in seconds – t, s.

For measuring the time **the stopwatch** is needed.

Refrigerant temperature
- On compressor input – t1
- On compressor output – t2

Air temperature
- On evaporator input – tp1
- On evaporator output – tp2

After performing measurements a chart should be prepared:

t1, t2, tp1, tp2, p1, p2 = f(t)

According to the chart, conclusions should be made

<u>It is also important to answer some practical questions about A/C system</u>

1. Does it work?
2. Does it work correctly ?
3. How do we know that it works correctly or not correctly ?

If the answer for question 2 is **NO:**

4. What is the reason that it is not working correctly ?
5. How do we know that this is the reason ?
6. What should be done to make it work correctly ?

If the answer for question 2 is **YES:**

8 FINISHED

LITERATURE

[1] Training Manuals - Toyota Motor Corporation

[2] J.Dowkontt. Teoria silników cieplnych. WKŁ 1974

or any basics of thermodynamics handbook.