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SECOP

OPERATIONAL DEFECTS IN HERMETIC COMPRESSORS AND REFRIGERATING SYSTEMS

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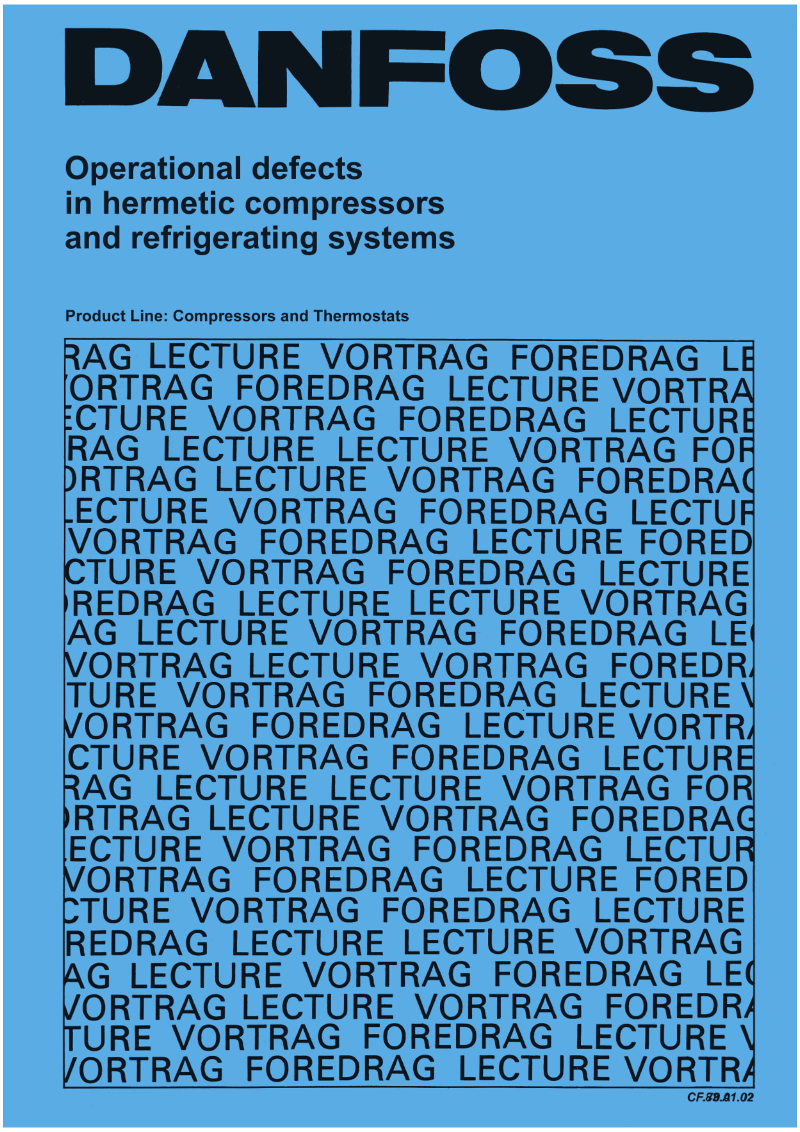

DANFOSS

Operational defects
in hermetic compressors
and refrigerating systems

Product Line: Compressors and Thermostats

OPERATIONAL DEFECTS IN HERMETIC COMPRESSORS AND REFRIGERATING SYSTEMS

The purpose of this lecture is to give comprehensive information on the faults which may possibly occur in hermetic refrigerating systems, no matter whether these are caused by faulty application or by defects of different nature.

To derive the expected benefit from the material it is necessary to have some experience in the use of hermetic compressors.

A thorough exposition of the subject, in the way this is described in the compendium, will take 3 - 3 1/2 hours, but depending on the qualifications of the audience it will often be expedient to leave out parts of the lecture.

The list of contents is at the back of this booklet; page 71-72

Operational Defects in Hermetic Compressors and Refrigerating Systems.

In the course of this lecture, a number of operational defects will be dealt with which may be encountered in hermetic compressors and refrigerating systems.

The subject mainly relates to compressors with single-phase motors and to refrigerating systems using capillary tube as metering device.

We shall first consider the electric components and their functions. Then, defects in the electric system will be dealt with, and finally, defects originating from the refrigerating system will be described.

It is reasonable to arrange the subject in this order, since a very large proportion of the defects in hermetic compressors originate from the electric system.
Multiple system defects are indicated by the electric components (e.g.by tripping of the motor protector).

1. The Electric Circuit.

The electric circuit of a hermetic compressor with a single-phase motor is shown in Fig.1.

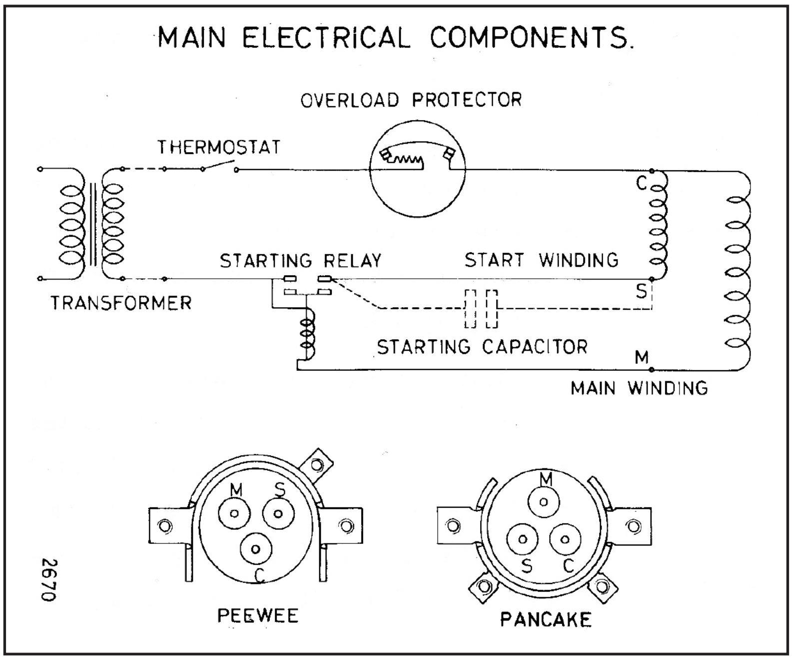


Fig.1

The components of the circuit are:

Motor
Starting relay
Motor protector
Thermostat

and, if required,

Starting capacitor and
Transformer.

From the diagram it can be seen that there are two parallel circuits. One of these runs through the coil of the starting relay, the main winding of the motor, and thence through the motor protector and the thermostat.

The other circuit is used when the starting relay is actuated, and runs through the auxiliary winding (also called the starting winding).

The connection between the motor and the electric auxiliary components is through a hermetically sealed terminal which is welded to the compressor housing.

The "pins" of this terminal are insulated by glass from the surrounding material.

The way in which the motor is connected to the terminal should be noted. On the PEEWEE compressor, the orientation is ^{M} C ^{S}°). On the PANCAKE compressors, which are not longer manufactured, the orientation was S ^{M} C. As will be seen, this is another arrangement but the same order read from left to right and one line at a time.

If you cannot remember the order of the motor connections, it is always possible to measure the resistance with an ohmmeter between the three pins, one by one. The resistance in the main winding is measured between M and C. The resistance in the starting winding is measured between S and C. The resistance in the starting winding is always the larger of these two resistances.

Since the resistance between M and S is the sum of the resistances in the main and starting windings, the order of connection can be deduced. (See Fig.2).

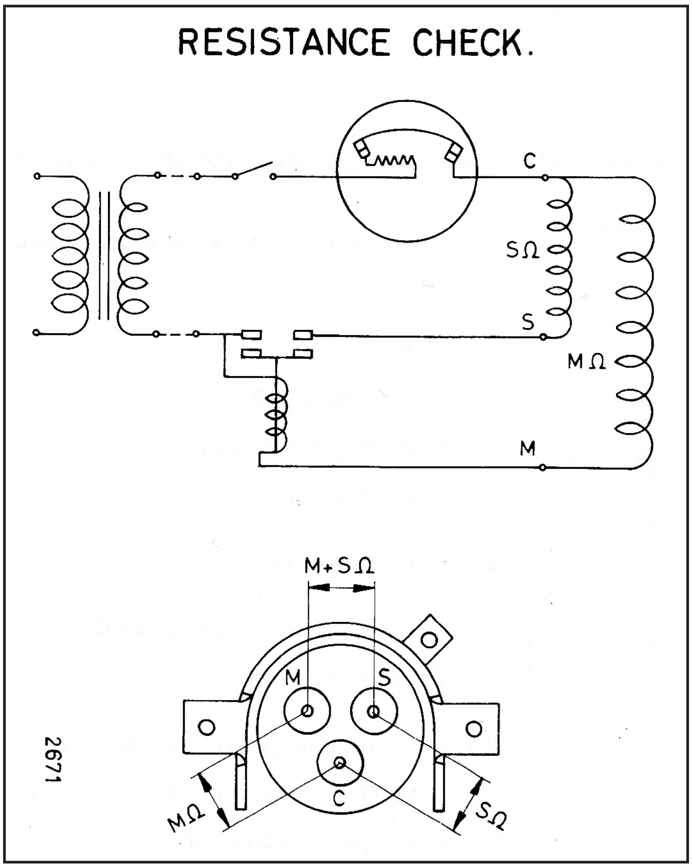


Fig.2

The motor is a single-phase asynchronous motor with resistance (or capacitor) starting.

The motor has two sets of windings; the main (run) winding and the auxiliary (starting) winding.

The starting winding, which is of thinner wire and has a higher resistance than the main winding, normally only functions at the moment of starting and while the motor is gaining speed.

The relatively high resistance of the starting winding results in a high rate of temperature increase - often as much as 10°C~18°F per second. Since it is not desirable that the starting winding temperature should exceed 150-160°C~300-320°F at any time (depending on the type of insulant), it is obvious that the winding should be subjected to starting current for only a very short time. In fact during normal starting, the start winding is active for a fraction of a second only. If correct starting is delayed, the motor protector must quickly take over.

°) In other technical literature we have used the following symbols:
U instead of M (run), Z instead of S (start) and V instead of C (common).

Some important motor characteristics are:

- Starting torque
- Starting current
- Breakdown torque
- Number of revolutions

The starting torque is a measure of the rotational resistance which the motor can overcome.

Distinction is made between motors with high starting torques and motors with low starting torques.

Motors with high starting torques, denoted HST, can be used in systems with an expansion valve. HST compressors are equipped with a start capacitor.

Motors with low starting torques, denoted LST, can only be used in systems with pressure equalizing between the condenser and evaporator during standstill periods. Hence, LST compressors are only used in systems with capillary tube injection.

The starting current, which is also termed the short-circuit current, is a measure of the amount of current consumed by the motor at the moment of starting. When fuses are blown in the supply mains, this is generally due to the fact that the fuse rating does not match the starting current of the motor, perhaps because the group is subjected to another load at the same time.

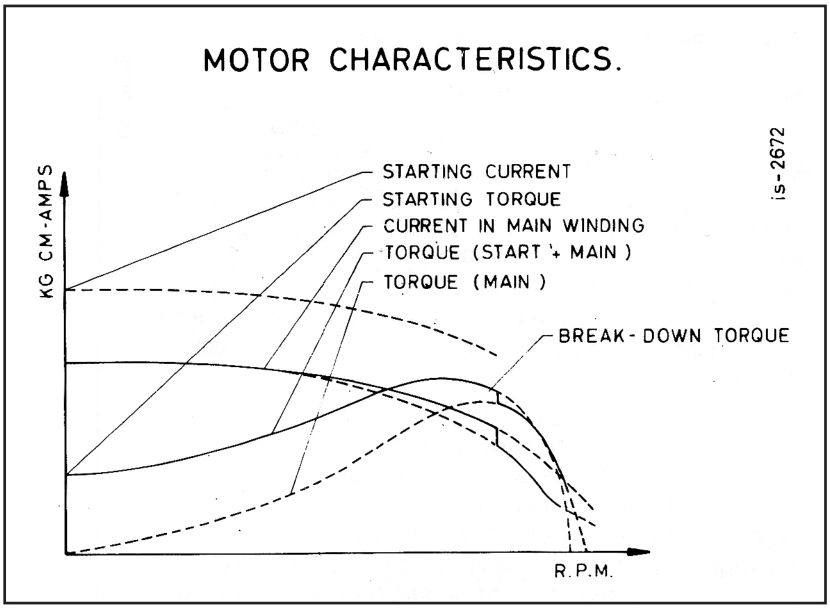


Fig.3

The breakdown torque is an indication of the maximum load to which a motor can be subjected during operation.

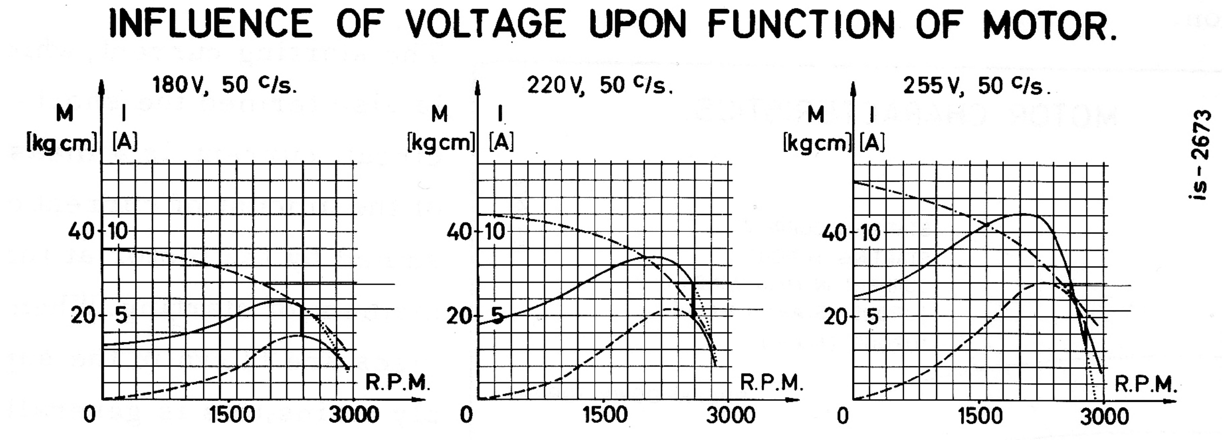
If a motor in operation is loaded with a torque exceeding the breakdown torque, it will slow down and stop. On a hermetic compressor, the starting relay and motor protector will, however, react before this point and cut off the current supply.

The motors of PEEWEE compressors are 2-pole, i.e. the synchronous speed is 3000 RPM at 50 c/s, and 3600 RPM at 60 c/s.

The PANCAKE compressors, which went out of production some years ago, had 4-pole motors, i.e. the synchronous speed was 1500 RPM at 50 c/s and 1800 RPM at 60 c/s.

Fig.4 shows acceleration curves for a PEEWEE compressor motor during undervoltage and overvoltage supply. The curves illustrate the fact that currents and torques increase with the voltage. Under certain conditions, this can be utilized. There may be times when it is difficult to start the compressor, even though nothing is actually wrong with it. Thus, it may be necessary to start compressors from a very cold condition, when this is difficult due to the increased oil viscosity. By using a variotransformer, starting may be tried by supplying overvoltage, so that adequate starting and breakdown torques are available.

Other situations may occur. Thus, for example, it may often be difficult to carry out the initial start-up of a compressor which has been stored for a lengthy period, whereas as soon as the compressor is running and thoroughly lubricated, there are no problems. In this instance overvoltage can also be used. Motor failure can be ascertained most easily by checking the resistance in the windings. If an ohmmeter is connected to the "common" and "run" terminals, the resistance of the main winding can be determined.
The resistance in the start winding is determined by measuring across the "common" and "start" terminals.
If the resistance is "infinite", the circuit is interrupted. If the resistance deviates considerably from the value applicable to the motor



UNDER-VOLTAGE:

LOWER STARTING TORQUE.
LOWER STARTING CURRENT.
LOWER BREAK-DOWN TORQUE.
DEFECTS POSSIBLE AT CRITICAL VOLTAGE.
NO START (TRIPPING OF MOTOR PROTECTOR).
MOTOR STALLING (RE-ENERGIZING OF START WINDING - TRIPPING OF MOTOR PROTECTOR).

OVER-VOLTAGE:

HIGHER STARTING TORQUE.
HIGHER BREAK-DOWN TORQUE.
HIGHER AMPERAGE.
POOR EFFICIENCY OF MOTOR.
DEFECTS POSSIBLE AT CRITICAL VOLTAGE.
TRIPPING OF MOTOR PROTECTOR CAUSED BY HIGH AMPERAGE - HIGH WINDING TEMP.)

Fig.4

type, short-circuiting is involved.

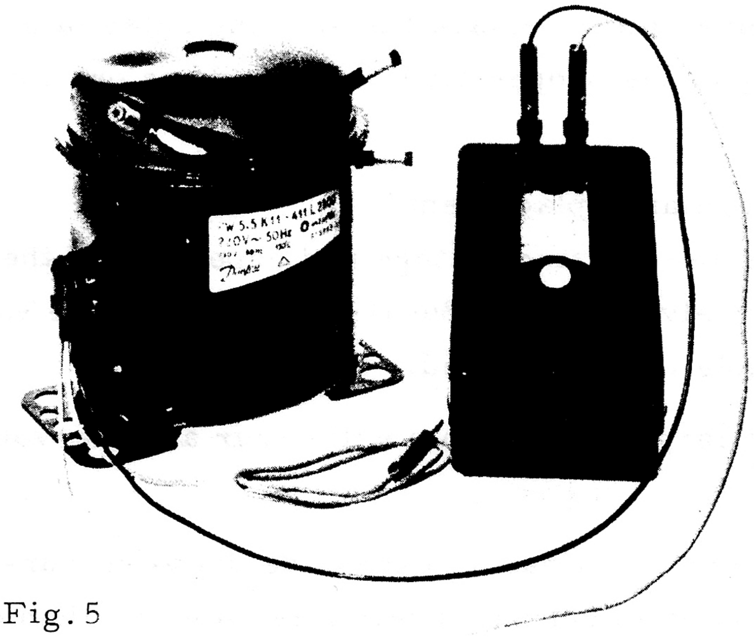


Fig. 5

Starting relay: A current-dependent electromagnetic starting relay is used for cutting in and out the motor starting winding in PEEWEE compressors. The currents required to cut in and out the switch are characteristic data for relays of this type.
When the relay coil and the main winding of the motor are subjected to a sufficiently high current, e.g. the starting current, the relay armature is picked up and the switch makes circuit to the starting winding. During the acceleration of the motor, the current through the main winding and the relay coil falls. When the current has fallen to a value corresponding to the cut-out current (drop-out current) of the relay, the relay armature drops and the current through the starting winding is interrupted. (See Fig.6).

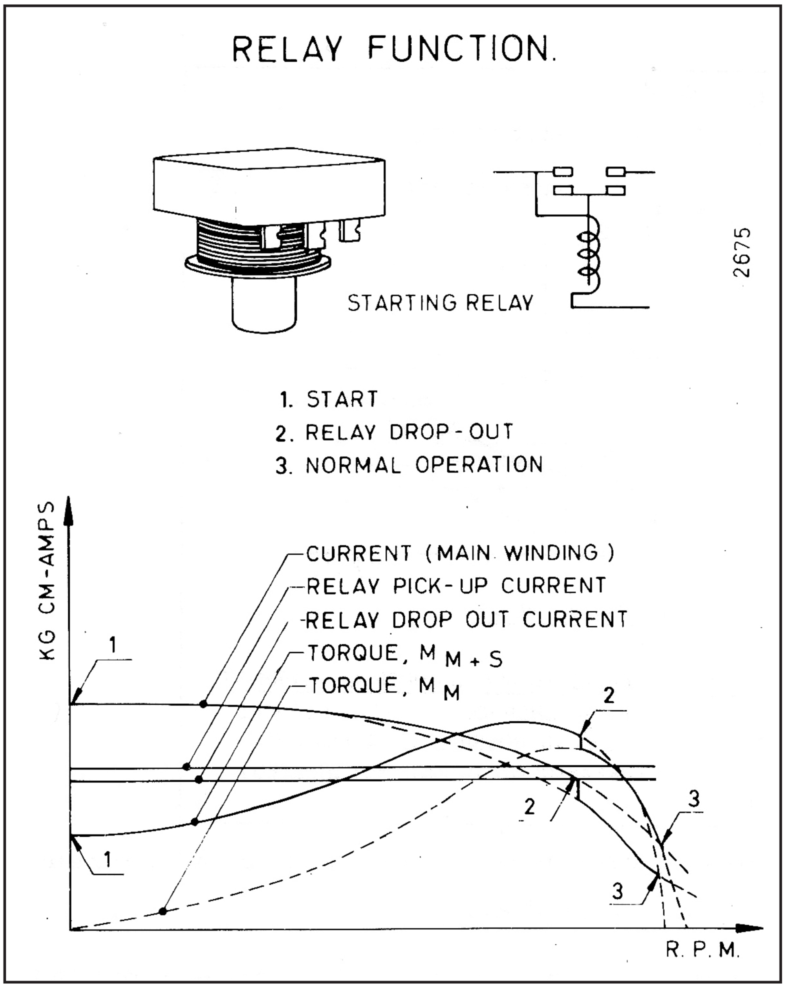


Fig.6

Of course it is not unimportant at which speed of rotation the start winding is disconnected.

Optimum motor utilization results when the relay is cut out by a current equating to the maximum torque of the motor (breakdown torque)
Hence this is the criterion for relay selection, regard being paid at the same time to the fact that proper functioning must occur at

reasonable over- and undervoltages. Since the relay is entirely responsible for correct motor utilization, it goes without saying that the relay designed for the motor size in question cannot be casually replaced by another which happens to be at hand.

Imagine a situation where the serviceman must replace the starting relay of a compressor. He does not have a relay of the proper size, only perhaps one for a larger or smaller compressor.

What will be the result of such an irregular replacement?
If the compressor in question is subjected to rated voltage and especially if the load is small, irregularities will scarcely be noted. But the moment voltage variations and increased load occur, trouble is experienced. If the serviceman uses a relay from a larger motor,this Will occur at undervoltage.

Fig.7 shows such an example. The wrong relay has an excessive drop-out current. This means that the starting winding is cut out at fewer revolutions than desired. The more pronounced the undervoltage, the sooner the relay drops out. If the motor load at the moment of drop-out is higher than the torque without the start winding cut in, the motor will slow down and stop.
In practice, the relay will cut in, cut out, and cut in again a few times until the motor protector breaks circuit.

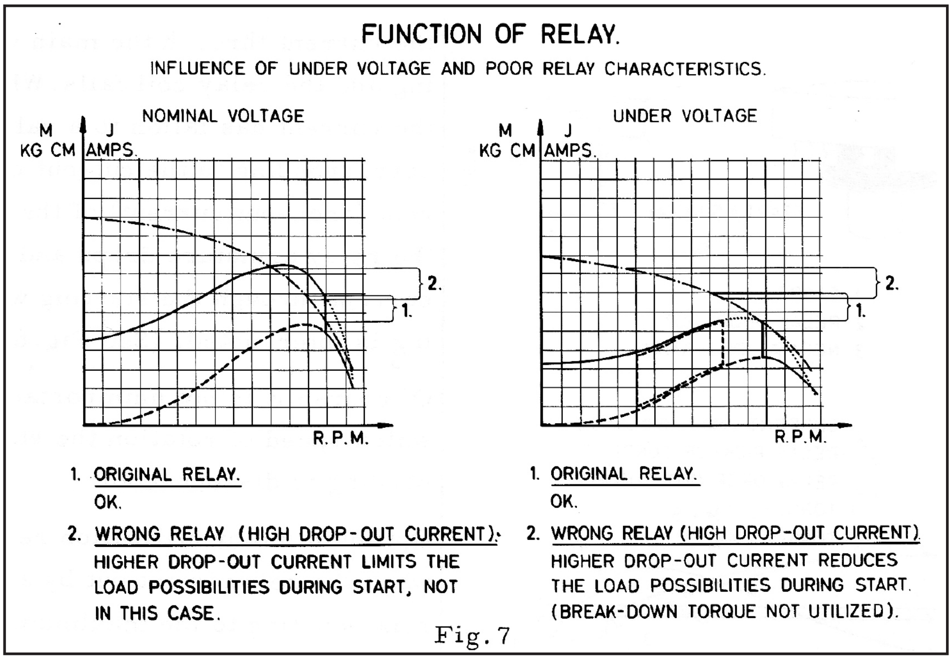


Fig.7

Fig.8 shows an example in which a relay is used with too low a drop-out current. Trouble will in this case be experienced at overvoltage.

The illustration shows that the motor will never run at so little current input that the relay can drop out. The motor protector will therefore soon begin to operate.

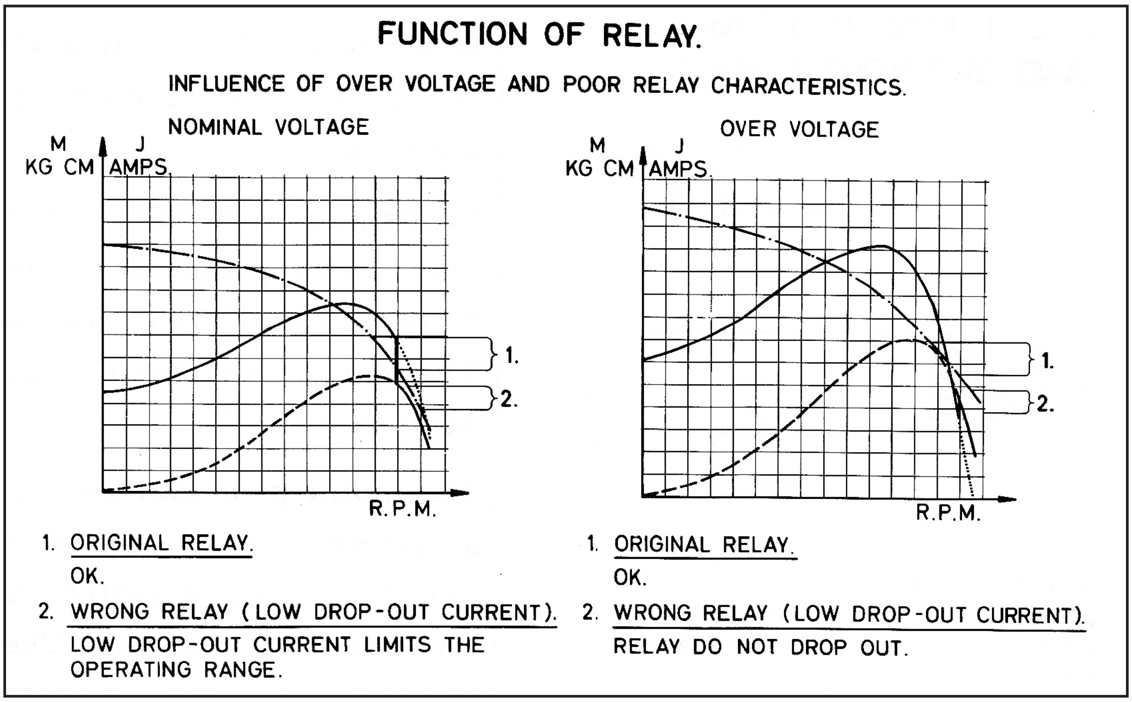


Fig.8

The purpose of the examples shown is, of course, to stress the importance of the use of only the correct relay for the motor in question.

The design and operating principle of the starting relay result in proper functioning only being achieved when the relay is fitted in the correct vertical position. Thus, if during service the electrical equipment or relay is left "lying" beside the compressor, proper functioning will not be achieved. It will be doubtful whether the relay cuts in, but if it does, drop-out cannot take place.
The motor protector is not calculated for this condition, and proper function cannot always be expected. A burnt-out start winding may be the result.

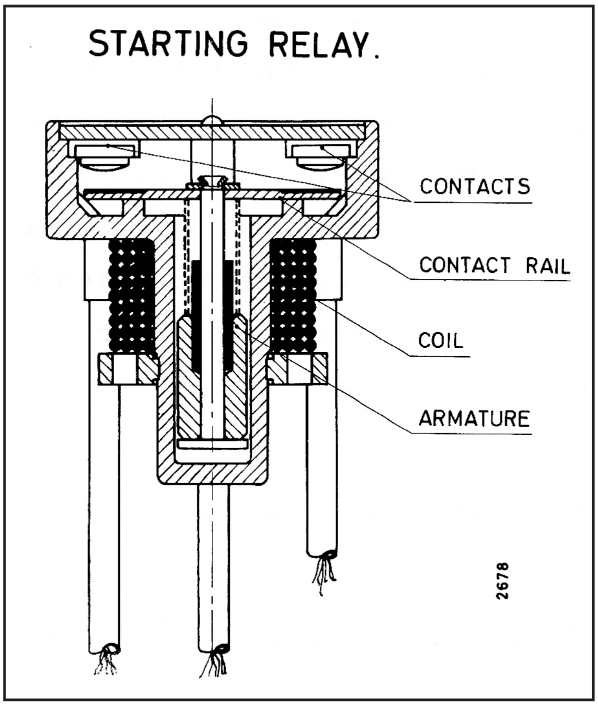


Fig.9

Possible defects in the starting relay are:

Burnt contacts, breaks in the relay current coil, and mechanical defects(e.g. foreign matter) which prevent the cut-in and drop-out of the relay.

A starting relay can be tested for correct functioning by rechecking the specifications, i.e. "pick-up current" and "drop-out current".

Fig.10 shows an arrangement suitable for the purpose.

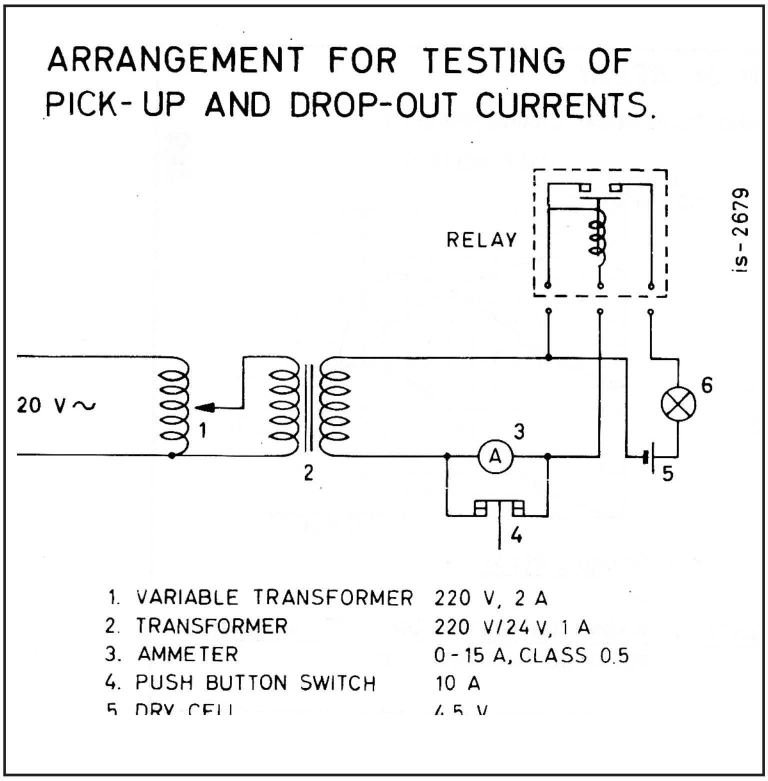


Fig.10

The object of the motor protector is to protect the motor against overloading during starting and operation.

On Danfoss PEEWEE compressors,motor protectors of the socalled "Klixon" type are used. The motor protector design will be seen from Fig.11.
The motor protector consists of an electric heater, a dished bimetal disc, and a switch, all built into a bakelite housing. The bimetal disc is actuated partly by the temperature of the ambient air (heat radiation from the compressor housing), and partly by heat radiation from the electric heater.

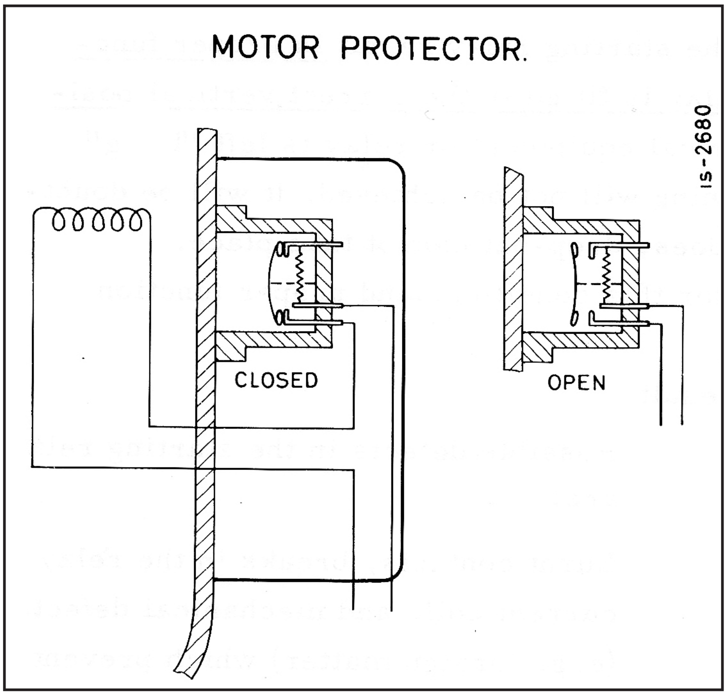


Fig.11

In the electric circuit of the compressor, the motor protector is incorporated in such a way that the total power consumption of the motor passes through it continuously.

The factors which decide whether the motor protector is actuated are, in part the transformation of energy in the electric heater, and in part the heat radiation from the compressor housing. The current consumed by the motor and the temperature of the compressor housing are, therefore, the factors which control the occurrence of the so-called Klixon trips.

Fundamentally, effective protection of both the starting and main windings of the motor is required.

Maximum power consumption takes place at the moment of starting. If the rotation of the rotor is impeded, this current consumption may be of long duration, so that the start winding is rapidly heated up, often at a rate of up to 10°C~18°F per second. It is, however, not advisable to permit starting winding temperatures of much more than 150°C~302°F. (This limit is, however, dependent to some extent on the quality of the wire insulation used).

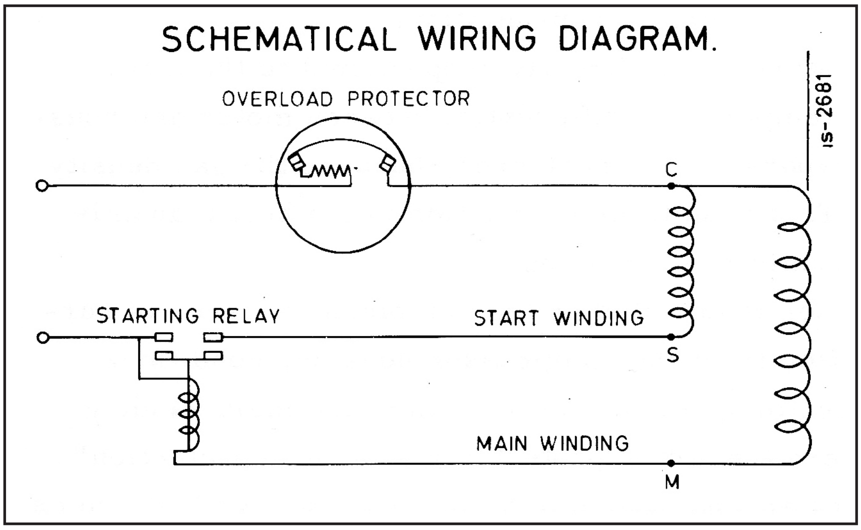


Fig.12

Under these conditions, which are termed "locked rotor", a rapidly reacting motor protector is obviously required. The "Klixon" -type motor protector gives excellent protection.

It is easy to understand that the reaction rate of the motor protector is absolutely critical for suitable protection. The short-circuit current of the motor is, therefore, an important criterion for selecting the motor protector for a given compressor.

For the same reason, it is very important that only the type of motor protector which is recommended by the compressor manufacturer should be used. If a motor protector for a compressor motor is replaced by a motor protector designed for a higher current (a larger motor), this will very soon result in burning-out of the starting winding.

The motor protector also reacts if the starting winding is cut-in during operation. Such a situation may occur, for example, when the motor is overloaded so that the relay is cut-in during operation (motor stalling), or when the relay does not cut-out the starting winding soon enough after the start. This may be due to defects in the relay or abnormal load conditions during acceleration.
As earlier mentioned, the "Klixon" -type motor protector affords excellent protection against overloading of the starting winding.
It is somewhat more difficult to establish perfect protection of the main winding. Overloading of the main winding occurs when the motor is subjected, for a long period, to temperatures above the temperature limit applicable to the wire insulation.
The lifetime of any insulating material is determined by the interplay of temperature and time. If a given insulation is used at a high temperature, its lifetime will be shorter than when the same insulation is used at a lower temperature.
The temperature limit applying to the insulating material can be exceeded when a compressor is subjected to poor cooling conditions, abnormal

overvoltage,undervoltage, very high condensing pressure, or when the gas-cooling of the compressor motor is deficient due to the suction side pressure being abnormally low, e.g. because of loss of charge.
However, not all these factors result in increased current consumption. Loss of charge may even give rise to reduced current consumption.
The compressor housing temperature is not directly proportional to the motor temperature. For example, the temperature differential between motor and housing will increase at minimum evaporating temperatures, because the gas density is reduced at lower pressures. This results in a reduction in the heat transmission between the motor and the compressor housing.
Since the "Klixon" motor protector is actuated by the combined influence of current consumption and heat radiation from the compressor housing, conditions may occur where the motor protector gives fair protection of the main winding, just as conditions may occur where the motor protector gives "overprotection".
Hence, external motor protectors are something of a compromise, when it comes to protecting the main winding. Experience shows, however, that burnt-out main windings very seldom occur with the compressor sizes used in domestic refrigerators. This is an indication that the protection principle used works satisfactorily in practice.

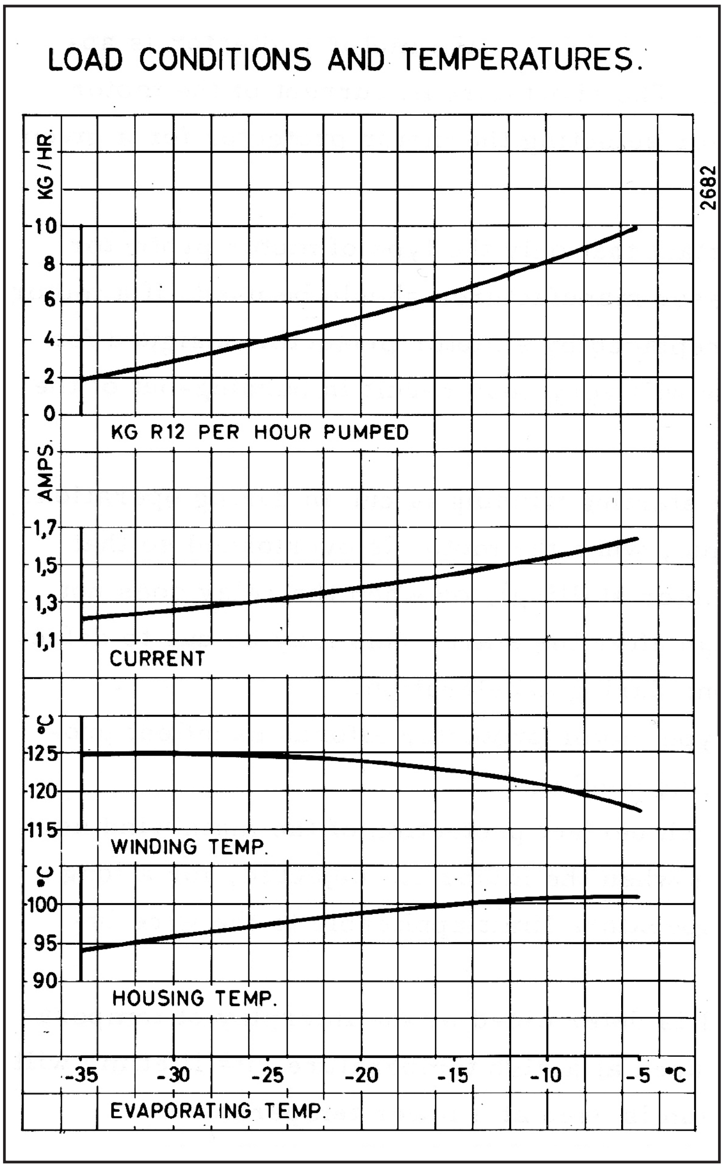


Fig.13

In Fig. 13 the relation between the load (evaporating temperature), current consumption, winding temperature, and housing temperature is shown.
Under the conditions shown here, the proper protection of the main winding can only be obtained if the motor protector can "sense". directly on the motor windings. Protective devices of this nature, the so-called winding protectors, are already in use on large hermetic compressors, e.g. in air–conditioning plants. Within the range of PEEWEE compressors, the winding protector is used only in model PW11X25.

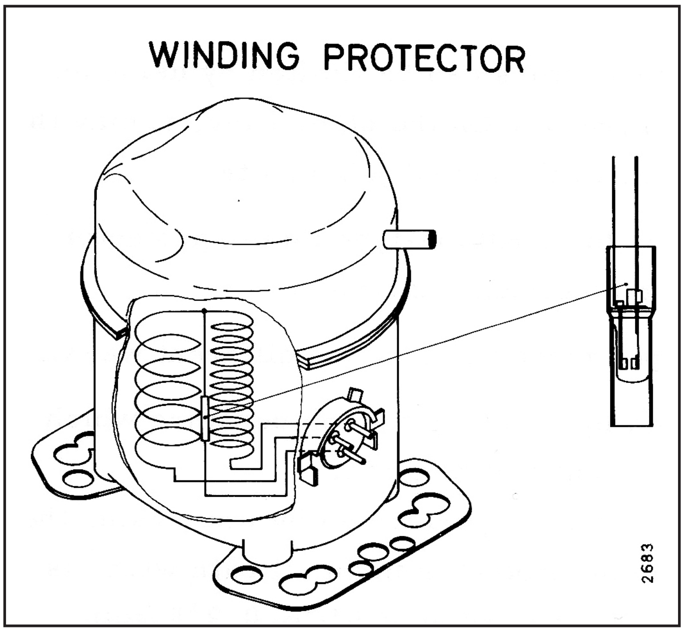
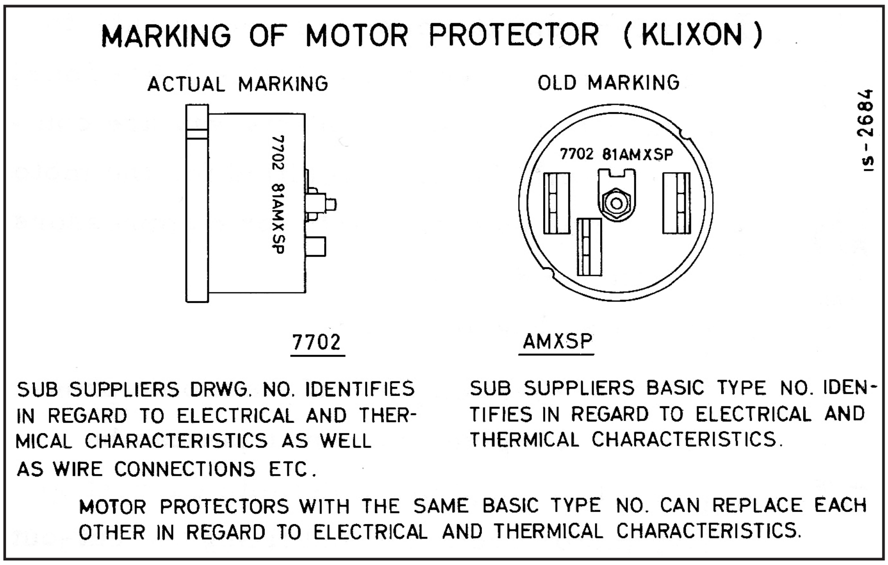


Fig.14

Fig. 14 shows diagrammatically the location of the winding protector in the electric-circuit.

The function of the motor protector is to protect the compressor against overloading. Therefore, preliminary cut-out of the motor protector need not necessarily be an indication of defects in the compressor or refrigerating system. If, on the other hand, cut-outs occur at short intervals so that proper refrigeration does not take place, precautions must be taken. (Circumstances will be described later which causes the motor protector to trip).

Under normal conditions of use, the motor protector has a very long life. When eventually replacement is necessary, this is generally due to the electric heater being burnt out.



SUB SUPPLIERS DRWG. NO. IDENTIFIES IN REGARD TO ELECTRICAL AND THERMICAL CHARACTERISTICS AS WELL AS WIRE CONNECTIONS ETC.

SUB SUPPLIERS BASIC TYPE NO. IDENTIFIES IN REGARD TO ELECTRICAL AND THERMICAL CHARACTERISTICS.

MOTOR PROTECTORS WITH THE SAME BASIC TYPE NO. CAN REPLACE EACH OTHER IN REGARD TO ELECTRICAL AND THERMICAL CHARACTERISTICS.

Fig.15

Since the motor protector is directly connected between mains and motor, defects in it will result in the compressor being switched off.

As mentioned earlier, it is important when replacing a motor protector to use only an approved type.
T.-H.N.2.4.1. and 2.4.3. indicate which motor protectors can be used for the different Danfoss compressors.
The motor protectors are characterized by three different numbers: the Danfoss No., the subsupplier's No., and the so-called basic type No.
The latter two Nos. are engraved or stamped on the bakelite housing of the motor protector.
Motor protectors with the same basic type No. need not have the same Danfoss No. or the same subsupplier's No., as these two numbers, besides referring the thermal and electrical properties, also provide clear identification of the connections (wires, clips, terminals).

Most servicemen prefer to carry a limited number of motor protectors on their rounds. The number of different motor protectors can be limited by using an assortment, merely according to Basic Type No. On the other hand, it may then be necessary to adapt the connecting wires to the actual job on site.

Always remember that the Basic type No. for a Klixon-type motor protector gives a clear definition of its thermal and electrical functions.
A motor protector can be tested for proper functioning in two different ways.
a) Its thermal performance can be tested by checking the temperature which is necessary to make the bimetal disc cut out and in again.

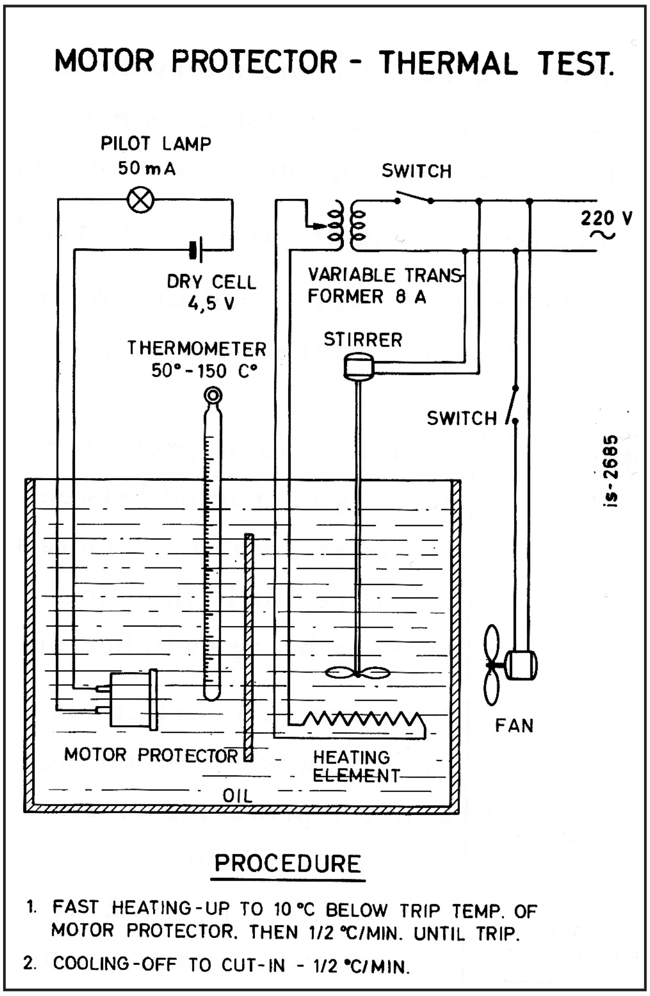


Fig.16

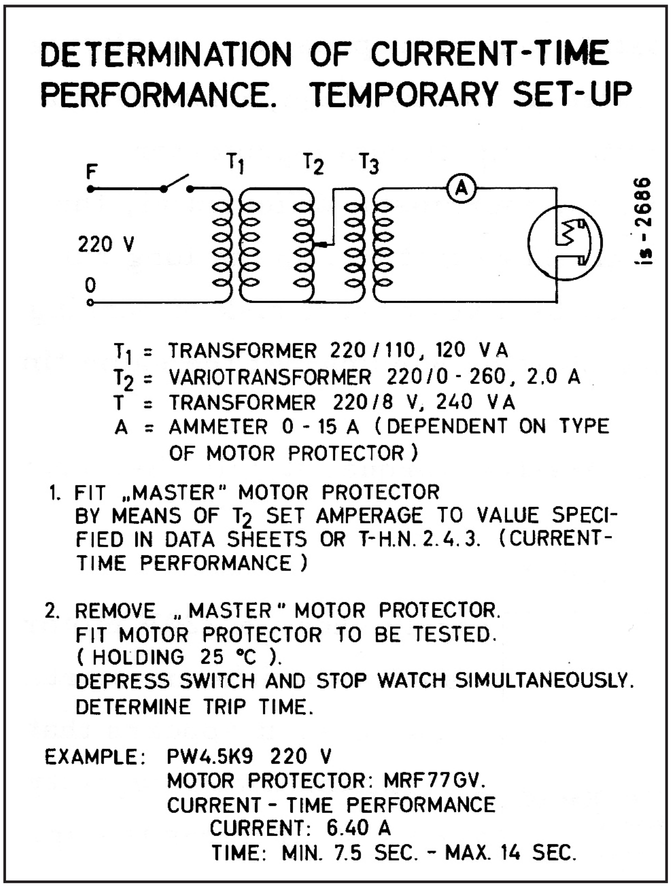
The test is performed by immersing the motor protector in an oil bath which is slowly heated at 0.5°C~0.9°F/min.
The cut—out is checked by means of a pilot lamp (50 mA) connected in series with the motor protector, in a circuit with a 4.5V dry cell. When the motor protector is cut-out, the oil bath is slowly cooled until the motor protector cuts-in again (rate of cooling 0.5°C~0.9°F/min). The data determined in this way are compared with the data specified for the motor protector on data sheets for compressors or on T.-H.N.2.4.3.
See also Fig.16.

b) The reaction time of the motor protector at a given current input can be tested by supplying a definite current to the motor protector and fixing the cut-out time.
Prior to testing, the temperature of the motor protector must be 25°C~77°F. To be carried out as prescribed, the test requires a special arrangement. However, a simple arrangement as shown diagrammatically in Fig.17 can also be used.
It will often be enough to check that the motor protector can cut-out.
This can be arranged, either by using the thermal test described under a), or by supplying the motor protector with current equal to the starting current of the compressor motor.

The purpose of the starting capacitor is to increase the ratio of starting torque/starting current. In other words: the starting capacitor is used to

increase the starting torque of a motor, without increasing the starting current at the same time. In other cases, the starting capacitor is used to reduce the starting current while maintaining the starting torque.
Fig.18 shows acceleration curves for an LST motor without and with a starting capacitor, respectively. The effect of the capacitor on the starting torque and the current should be noted.

In the present range of Danfoss compressors, starting capacitors are used on HST—versions only. (Previously, there was an LST model denoted 1/3HP LST/LBP. This model, which was equipped with a 20 µF starting capacitor for reducing the starting current, was deleted from our programme in 1963).



DETERMINATION OF CURRENT-TIME PERFORMANCE. TEMPORARY SET-UP

T_1 = TRANSFORMER 220 / 110, 120 VA
T_2 = VARIOTRANSFORMER 220 / 0 - 260, 2,0 A
T = TRANSFORMER 220 / 8 V, 240 VA
A = AMMETER 0 - 15 A (DEPENDENT ON TYPE OF MOTOR PROTECTOR)

1. FIT „MASTER" MOTOR PROTECTOR BY MEANS OF T_2 SET AMPERAGE TO VALUE SPECIFIED IN DATA SHEETS OR T-H.N. 2.4.3. (CURRENT-TIME PERFORMANCE)
2. REMOVE „MASTER" MOTOR PROTECTOR. FIT MOTOR PROTECTOR TO BE TESTED. (HOLDING 25 °C). DEPRESS SWITCH AND STOP WATCH SIMULTANEOUSLY. DETERMINE TRIP TIME.

EXAMPLE: PW4.5K9 220 V
MOTOR PROTECTOR: MRF77GV.
CURRENT - TIME PERFORMANCE
CURRENT: 6.40 A
TIME: MIN. 7.5 SEC. - MAX. 14 SEC.

Fig.17

A starting capacitor may be helpful under certain conditions during service on LST compressors.

If the combination of undervoltage-weak supply mains is experienced, starting difficulties may often occur, which will be the more pronounced, the higher the starting
current supplied to the motor.

As a starting capacitor can be used partly to increase the motor starting torque, and partly to reduce the starting current surge, it may often overcome the difficulties.
Similarly, a refrigerating system can be dimensioned in such a way that during the

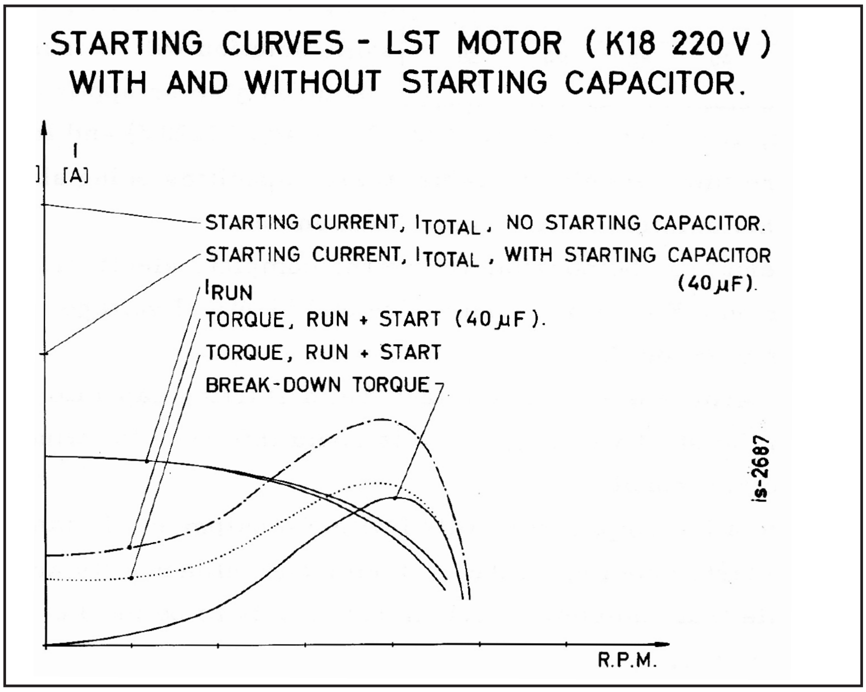


Fig.18

standstill periods, determined by the thermostat, sufficient pressure equalizing does not occur. Especially if the system operates at undervoltage, unsuccesful starting attempts may easily occur, with resultant trip of motor protector.
The cause of the failure may be in the system, the thermostat differential, the thermostat bulb position, or a combination of all these factors. In the long run, the situation will be precarious, since there will be a very great risk of burning-out the motor protector, and perhaps also the starting winding. At the same time, the cooling function may be unsatisfactory.
As a starting capacitor can increase the motor starting torque, it will often provide the most suitable solution to the problem.
But if so, which starting capacitor should be used?

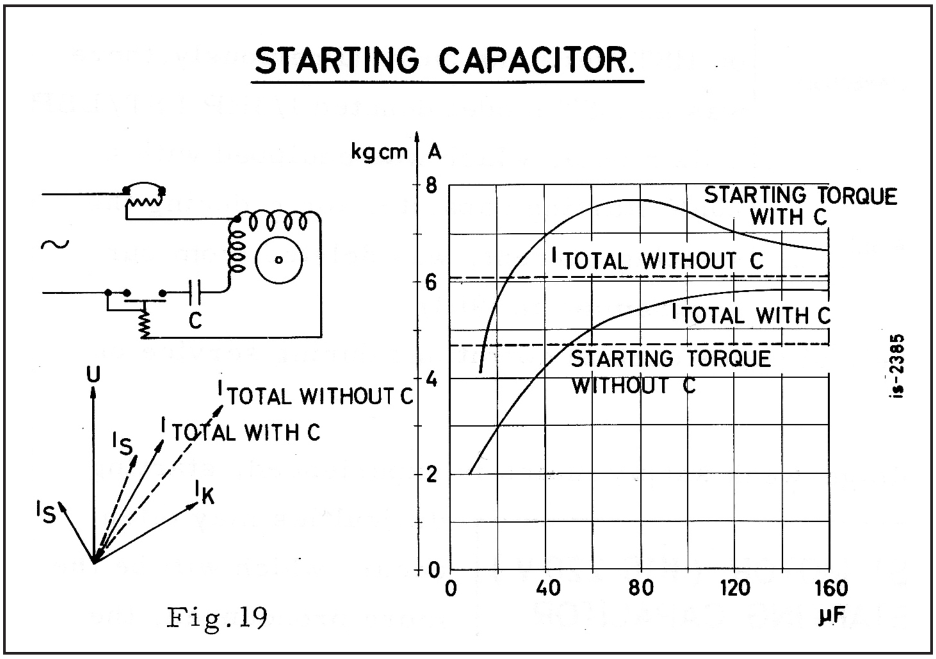
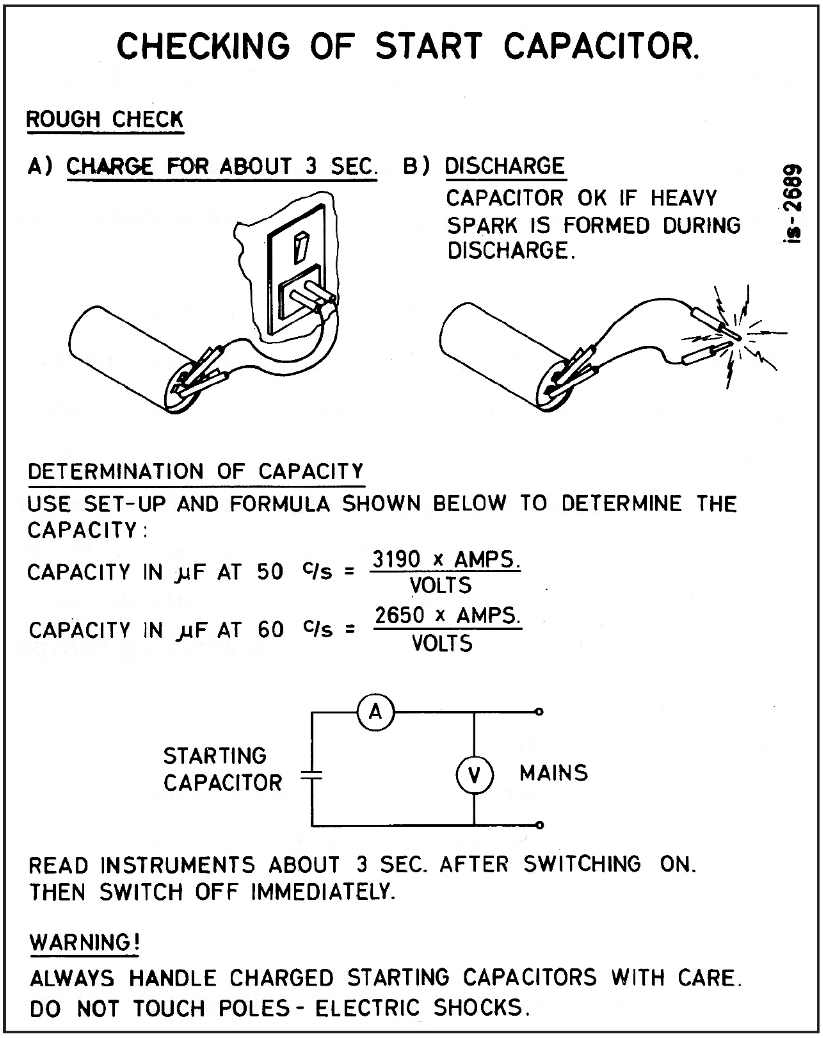


Fig.19

Fig.19 shows a 220V motor tested with different starting capacitors. It appears that a capacitor with a capacity of 60 - 80µF gives the optimum result. This applies to our smallest compressors (motors K6 to K11 - 1/12hp to 1/6 hp). For 110/115V motors the capacity will be four times as large - 240-320µF. The same solution will in many instances also be applicable to our largest compressors, i.e. motors K14 to K22. Since 40 µF (220V) and 160µF (115V) starting capacitors are immediately available (these capacities being already used on the HST models), this solution is often more convenient.
In many cases it Will, furthermore, be possible to use the complete electrical equipment from an X-motor on a K-motor of same size and identical voltage. The problem of mounting is thus overcome.
Something which should not be overlooked, is the fact that a starting capacitor alters current conditions in the start winding, and this could influence the winding protection under "locked rotor" condition.
This might be critical Where a K-compressor, fitted with X-equipment, is fan-cooled. This would lead to faster cooling of the protector and influence its action. We therefore keep to the rule that complete X-equipment is only to be used on K—motors with natural convection.
Note, that fitting a starting capacitor may affect the relay function.



CHECKING OF START CAPACITOR.

ROUGH CHECK

A) CHARGE FOR ABOUT 3 SEC.

B) DISCHARGE
CAPACITOR OK IF HEAVY SPARK IS FORMED DURING DISCHARGE.

DETERMINATION OF CAPACITY

USE SET-UP AND FORMULA SHOWN BELOW TO DETERMINE THE CAPACITY:

CAPACITY IN μF AT 50 c/s = $\frac{3190 \times \text{AMPS.}}{\text{VOLTS}}$

CAPACITY IN μF AT 60 c/s = $\frac{2650 \times \text{AMPS.}}{\text{VOLTS}}$

READ INSTRUMENTS ABOUT 3 SEC. AFTER SWITCHING ON. THEN SWITCH OFF IMMEDIATELY.

WARNING!

ALWAYS HANDLE CHARGED STARTING CAPACITORS WITH CARE. DO NOT TOUCH POLES - ELECTRIC SHOCKS.

Fig.20

In that case, relay drop-out at overvoltage is critical. However, it is generally the case that starting capacitors are not required at overvoltage as the starting torque will have been increased in advance. Be careful all the same, and check that the system operates properly at the maximum mains voltage which may be expected.

When dealing with a motor designed for capacitor starting, failure to start may be due to a defective start capacitor. Failure is most commonly due to short circuits or a "down to earth" condition; it is very important therefore, that the component be checked for these faults as a first step in diagnosis before any tests with mains voltages are considered. The diagnosis can be safely and quickly made with for instance a "Megger" or one of the special capacitor checking instruments now available at very reasonable cost. It should also be remembered that an electrolytic starting capacitor of these type used on HST Motors is designed by the manufacturer for intermittent use, normally 1.7%, which is understood to mean 3 seconds on line every 3 minutes which gives the normally accepted 20 starts per hour of the compressor. If then a capacitor of this type is allowed to remain across the mains voltage rapid overheating will occur, resulting inevitably in failure and possible bur sting of the container.

Having made these preliminary tests, a rough check can be made by connecting the capacitor to the main voltage and charging for no longer than 3 seconds, after which on discharge a heavy spark should be observed when the leads are shorted together.

If the capacity of the capacitor is unknown it can be determined by means of the arrangement shown in Fig 20

IMPORTANT A charged capacitor should always be handled with care since it could be fatal to touch the terminals!

The Transformer.

If a compressor is to be used on a supply mains with a voltage which varies markedly from the motor rating, a pre-transformer is mounted.
Such a transformer must ensure satisfactory motor operation, at the occurring voltage variations on the primary side, during starting as well as running. As the starting current may give rise to substantial voltage drops, the starting sequence may be become critical, especially if relative undervoltages already prevail on the primary side.
Therefore, the transformer has to be sufficiently "rigid" , i.e. it must be dimensioned adequately with a view to starting conditions. It will, normally, be a poor solution if the conversion ratio of the transformer is altered to improve the starting sequence. In this way, the start voltage may actually be increased, but at the same time undesirable overvoltage will result during running. At this time the current consumption is actually very low. If the primary side is at the same time subjected to relative overvoltage, the altered conversion ratio will result in the secondary voltage becoming critically high. The result will be high winding temperature and frequent protector tripping.
These conditions must be considered in each single case.
Normally is it not very difficult to obtain a transformer for a given purpose. However, it is imperative that the supplier is given correct and adequate information, as in the example below:

Example:

A 220V PW7.5Kl4 is to be used in a supply mains of 240V rated voltage. A conversion ratio for the transformer is selected as follows:
Primary/Secondary 240/220.
In view of the starting conditions, the compressor short-circuit current is specified, which according to the data sheets is 14.3 A at 220V.
Normal operation is estimated to take place at -25°C~13°F evaporating temperature and 55°C~131°F condensing temperature.
According to the data sheets, the compressor will consume 1.4 A under these conditions. A safety factor of 1.25 is selected.
The transformer must then be dimensioned for continuous operation at a load of 220•1.4•1.25 VA = 0.4 kVA.
It is now the task of the transformer supplier to ensure that the transformer can withstand the current surge mentioned above and at the same time to ensure that the compressor always receives a starting voltage which cannot be lower than the minimum starting voltage, also at the minimum primary voltage.
See also Fig.21.
In some countries, there are districts which frequently are subjected to abnormal undervoltage. Equally frequently, the same districts are probably subjected to normal voltage or even overvoltage. For example, abnormal undervoltage may be experienced in the daytime, and normal voltage or overvoltage at night.

DIMENSIONING OF TRANSFORMER.

EXAMPLE.

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CONDITIONS.

AN OIL-COOLED PW7.5K14, 220 V, IS TO BE USED AT A 240V MAINS (205V TO 265V).
THE REFRIGERATION SYSTEM RUNS SATISFACTORILY WITHIN THE VOLTAGE RANGE FROM 180 V TO 245 V.

DIMENSIONING.

RATIO SELECTED :
PRIMARY/SECONDARY = 240/220

START CURRENT AT 220 V 50 c/s	:	14.3 A
OPERATING CURRENT AT -25 °C / +55 °C	:	1.4 A
SAFETY FACTOR	:	1.25

PERMANENT LOAD (OPERATION):
220 V × 1.4 A × 1.25 ~ 0.4 kVA

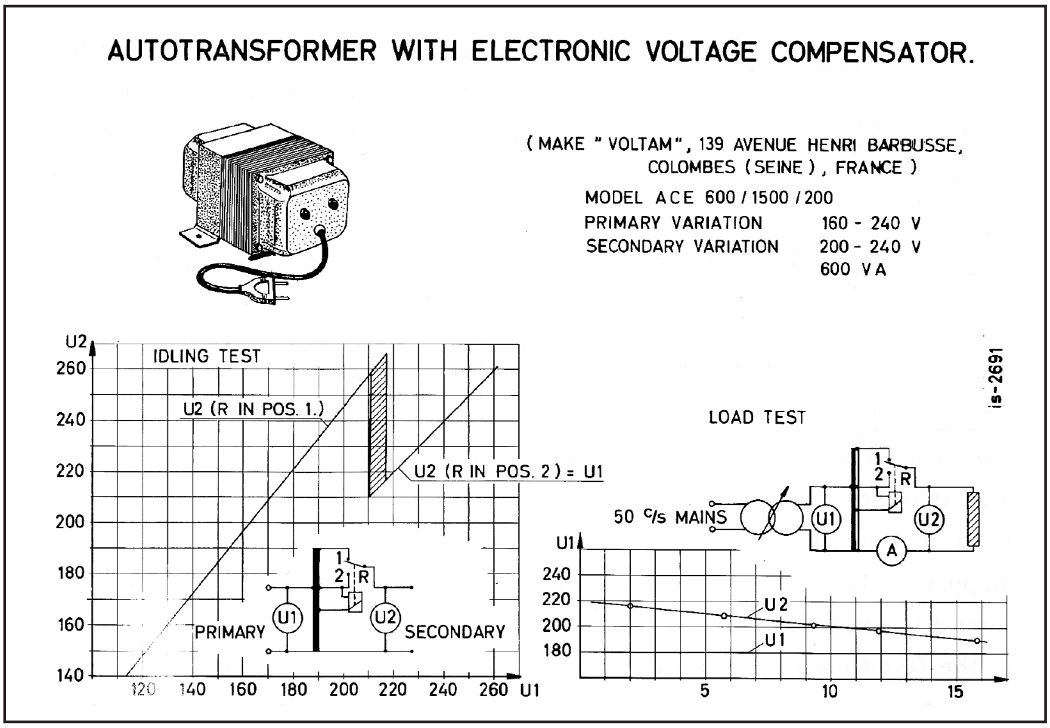
CHECK.

AT 265 V PRIMARY AND MIN. LOAD E SECONDARY MUST NOT EXCEED 245 V
AT 205 V PRIMARY AND CURRENT ABOUT 14 A E SECONDARY MUST NOT BE BELOW 180 V.

Fig.21

If the undervoltage is so low that the compressor cannot Work without a transformer, the dimensioning of the transformer may provide a dilemma. In such a case an autotransformer with automatic tap changeover can be used. However, this solution is rather expensive.

The firm of "Voltam" (139, Avenue Henri Barbusse, Colombes (Seine) France)
makes a transformer of this type.
The principle is that with undervoltage on the primary side a definite conversion ratio of e.g. 1:1.2 is achieved. The secondary voltage is thus about 20% higher than the primary voltage.
If, however, the primary voltage increases above a definite level, the tap-changing device (which is controlled by a Thyristor) begins to operate. Increased voltages then pass the transformer without being altered.
Fig. 22 shows some data for a transformer of this type. The transformer in question, which is called model ACE600/1500/220, was found usable for compressors with a motor size of up to K14 - 220V.
From Fig.22 it appears that the conversion is such that a primary no-load voltage of 160V — 240V results in a secondary voltage of about 200V - 240V.
The actual secondary voltages at 180V primary voltage and different loads also appear from Fig.22


AUTOTRANSFORMER WITH ELECTRONIC VOLTAGE COMPENSATOR.

(MAKE " VOLTAM", 139 AVENUE HENRI BARBUSSE,
COLOMBES (SEINE), FRANCE)
MODEL ACE 600 / 1500 / 200
PRIMARY VARIATION 160 - 240 V
SECONDARY VARIATION 200 - 240 V
600 VA

Fig.22

Wrongly dimensioned transformers will give rise to the following troubles:

At the moment of starting:	Symptoms as with weak supply mains or extreme undervoltage, i.e. starting trouble.
During operation:	Symptoms as with extreme overvoltage, i.e. a hot motor and protector tripping.

2. Electrical Failures. The Motor Protector Trips.

In this section we shall consider a number of faults, mainly in the electrical system, which affect the starting and running of the compressor. In several cases the motor protector hinders starting or running, even though the electric circuit is intact. We shall also consider some faults of this type originating from the system.
The section is divided into the following subsections:

- 2.1 Breaks in the electric circuit - The test lamp.
- 2.2 Breaks in the starting circuit.
- 2.3 "Locked rotor"
- 2.4 Undervoltage.
- 2.5 Tripping of the motor protector during operation.

2.1. Breaks in the Electric Circuit. Test Lamp.

When a hermetic compressor is connected to the supply mains but does not start, there may be multiple causes. But if there is no current consumption, and if the motor protector" does not react, the cause can only be a break in the electric curcuit. Let us have another look at a simple circuit diagram (Fig. 23).

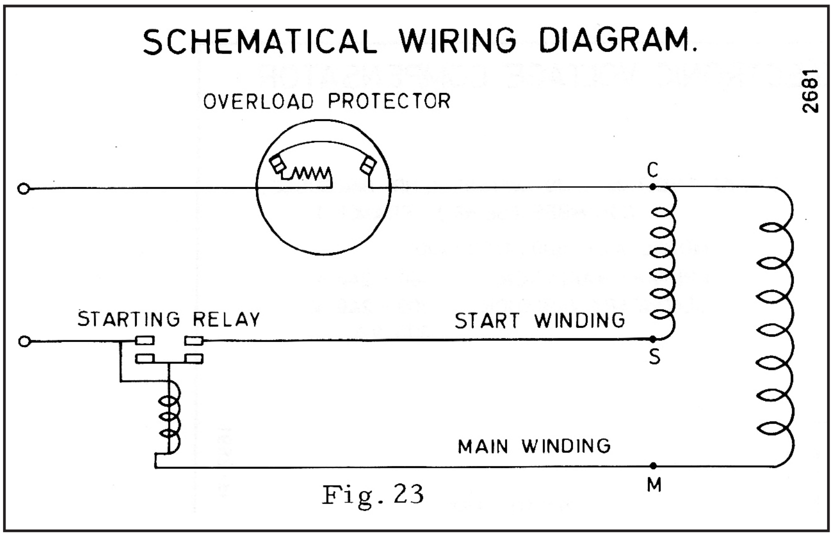


Fig. 23

It is evident from the diagram that there is a main circuit from the supply mains across motor protector, main winding, starting relay and back to the mains. Any interruption of this circuit results in nothing happening.
In such a situation it is natural first to check that the mains supply is live. The simplest method of doing so is by a polarity indicator. You may also connect an ordinary filament lamp to the plug socket and see whether it lights up. The best method is to use a voltmeter, to check if the voltage is correct (Fig.24). If the mains supply is dead, it goes without saying that, first of all, the fuses of the installation should be inspected.
Faults outside the fixed installation may be in the main components, or in the connections between these, i.e. the compressor (the main winding),

the motor protector the starting relay, the thermostat, and -perhaps- the transformer, if there is one.

To begin with, check that the thermostat is "closed".

Fault location then commences with a visual check on all connections to see whether they are intact.

The next inspection stage may be renewal of the compressor‘s electrical equipment, but often all components and wiring will be systematically examined. This form of fault location can be carried out by using a voltmeter or a test lamp. If a voltmeter is used, the electric circuit must be connected to the mains and should be systematically examined until the current break is located. It is, however, generally preferable to use a test lamp of the design shown in Fig.25.

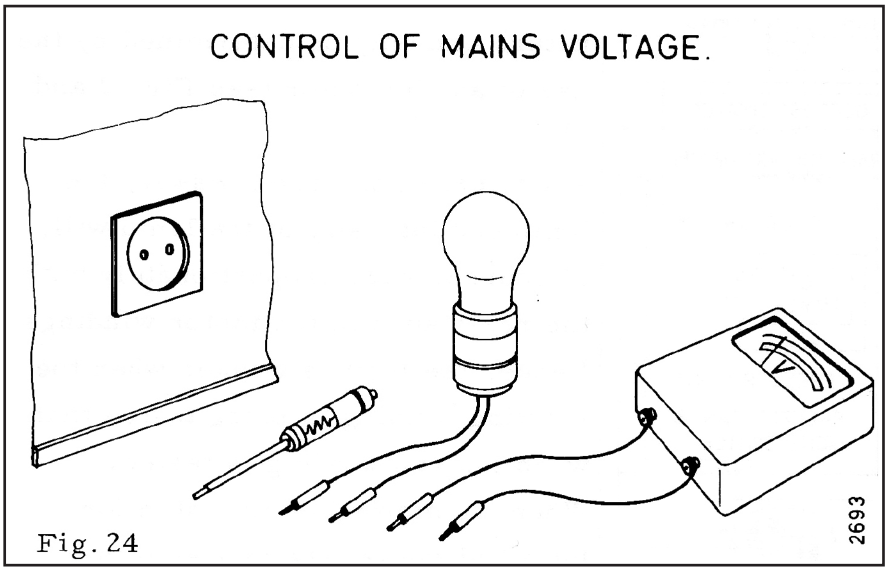


Fig. 24

The procedure is to chort-circuit the mains plug of the refrigerator. The test lamp is connected to the mains, and a check is made that the lamp lights up (by short-circuiting the electrodes). The circuit is then systematically tested for breaks.

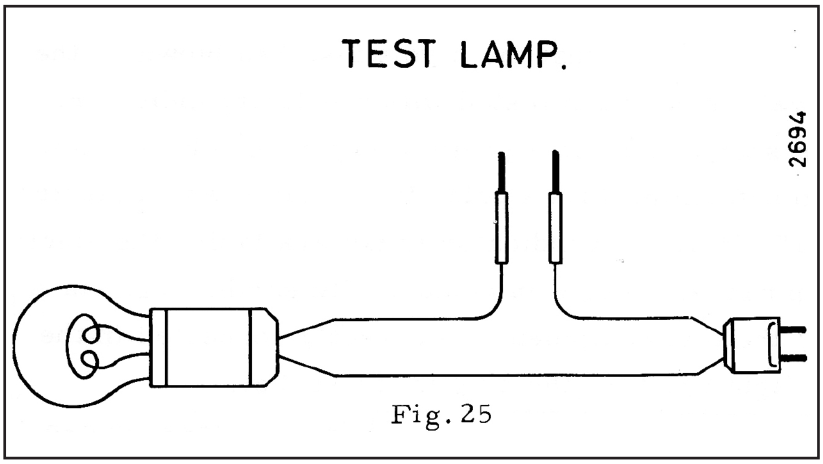


Fig. 25

The test lamp will not only be useful when testing a circuit as simple as the one shown in Fig.23. In more complicated refrigerators, fault finding is quite a different process, and the test lamp may be of use to locate a whole series of defects which need not necessarily affect the starting and running of the compressor.

As an example, Fig.26 shows a wiring diagram for an American dual temperature refrigerator which, as can be seen, offers considerably greater risks of circuit breaks than in the case on Fig.23.

The procedure for fault location in the electric circuit, of course, also includes the examination of the compressor itself. Connect one electrode of the test lamp to the terminal pin for "Common" connection. The other electrode is connected alternately to the "run" and "starting" connections respectively. If the lamp does not light up during these tests, there can be no doubt that the cause is an internal break.

If the lamp flashes, as for example when the compressor is shaken, this is due to a bad connection. If, on the other hand the light comes on and is constant, the connection may be assumed to be in order but this does not imply that the motor is entirely intact. If, for example, short-circuiting occurs in the motor (burning—out), the test lamp will not directly indicate this. Faults of this nature can only be determined by the use of an ohmmeter (see Fig.2 and 5).

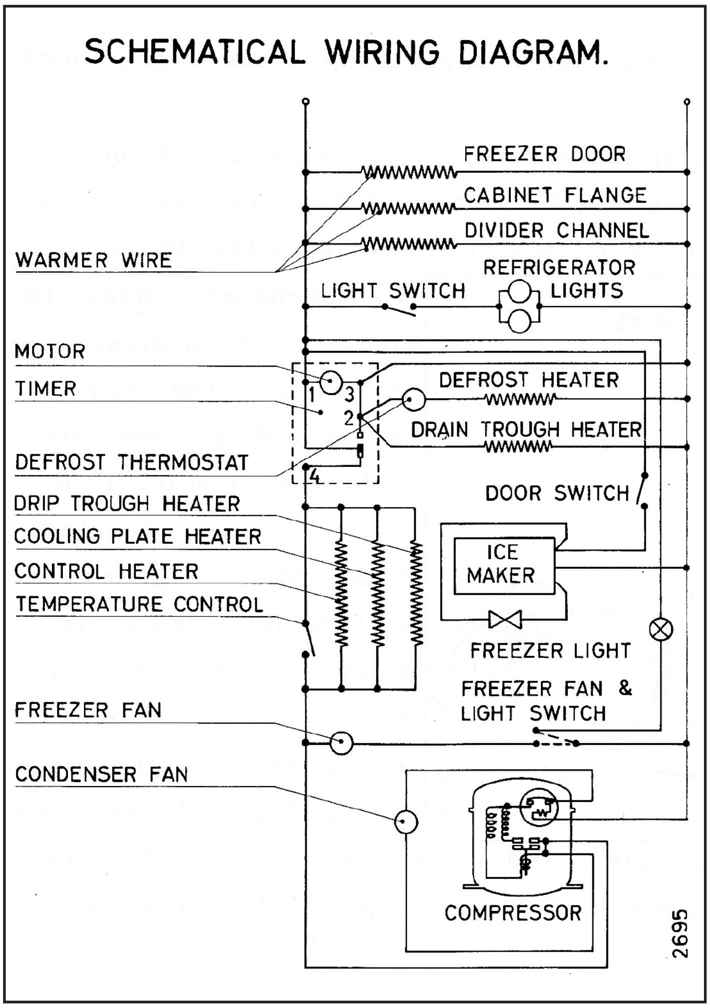


Fig.26

When testing the compressor, the luminous intensity of the lamp will, of course, vary proportionately with the resistance in the motor windings. Hence, the light is weaker when the starting winding is being tested than when the run winding is tested. When a compressor is tested for electrical faults, the test also includes leakage testing to earth. This is specially the case if it has been found during the first stage of fault finding that the mains fuse has blown or the refrigerator has proved to be "live", e.g. when tested with a polarity indicator. The test lamp can also be used in such cases for a preliminary rough check. However, it will then be necessary to determine with a polarity indicator which electrode is "phase" and which is "neutral" If such an indicator is not available, the electrode in direct connection with the lamp can be brought in contact with earth, e.g. via a water pipe. If the lamp lights up, the test equipment is correctly connected in the plug socket. If the lamp does not light up, turn the plug in the socket.

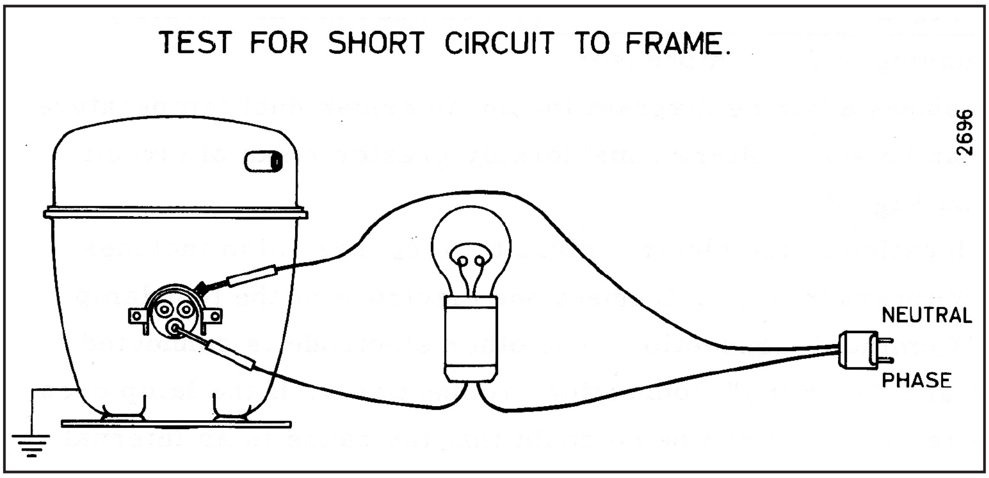


Fig.27

The compressor can now be tested for leakage to earth, with the electrode connected to the lamp and "phase" connected to the terminal pin for "Common" connection The other electrode which is connected to

"neutral" in the plug socket, is at the same time placed in non-insulated contact on the compressor housing, e. g. on the earth terminal. If the lamp now lights up, this shows leakage to earth.
By connecting the "phase" through the test lamp with one of the three terminals, the test will not be affected by a possible earthing of the compressor. The test lamp can, of course, also be used to check the complete refrigerator for leakage to earth. The procedure is then that the electrode which is connected to the lamp and "phase" is connected in turn to the plug pins. The other electrode is connected to a non-insulated point on the refrigerator.(earth connection)
In general, there is a certainty of leakage to earth when any electric object does not pass the test described, provided testing is correctly done. However, there is no certainty that an object which seems to pass the test is actually in order.
The test voltage is too low to indicate this. If it is desirable to be completely certain that there is no leakage to earth, it will be necessary to use a high—tension testing device. (e.g. 1500V) or a megohm—meter, if available.
We may now summarize the faults occurring when the compressor does not start and does not consume current. See Fig.28.

EFFECTS OF DEFECTS:

NO START OF COMPRESSOR - NO CURRENT CONSUMPTION - NO TRIPPING OF MOTOR PROTECTOR.

POSSIBLE CAUSES:

DEFECTIVE MAINS (BLOWN OUT FUSE).
DEFECTIVE MOTOR PROTECTOR.
DEFECTIVE STARTING RELAY (COIL).
DEFECTIVE THERMOSTAT.
DEFECTIVE MAIN WINDING.
DEFECTIVE TRANSFORMER.
DEFECTIVE WIRING.

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Fig. 28

2.2. Breaks in the Starting Circuit.

If the compressor main circuit is intact, but breaks occur in the starting circuit, the compressor will not start. In this case, the compressor will not consume full starting current, but only the portion for the main winding. For compressors without a starting capacitor (LST), the current will be 45-65% of the total starting current. For compressors with a starting capacitor (HST), the broken starting winding will - on the other hand - only reduce the current consumed to 90-95% of the total starting current.
If the starting circuits is interrupted, the motor protector will, of course, function, but the reaction time will increase proportionately to the current reduction.
The faults in the present case are:

Breaks in the starting winding
Defective (or incorrect) starting relay
Broken wires in the starting circuit

The actual source of error can easily be determined, checking first that the circuit is intact. This is done by means of the test lamp. Turn the starting relay upside down so that the contacts can close. If the fault is not located in this way, the starting winding resistance is measured with an ohmmeter, and the starting relay and the starting capacitor, if any, are replaced in turns.

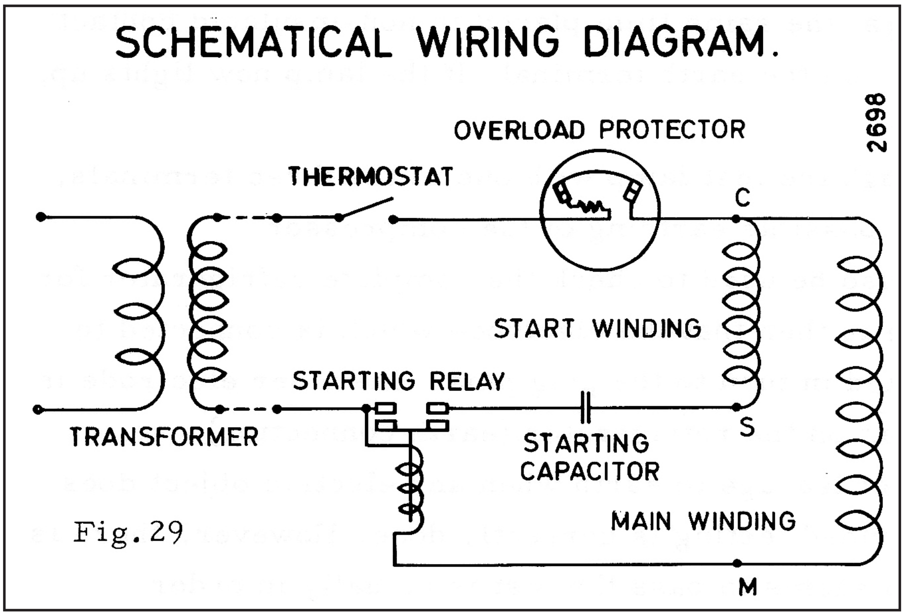

Fig.29

With faults of this nature, it may often be of advantage to determine beforehand whether the compressor motor is in working order. This is, of course, possible by testing the winding resistances.

But if an ohmmeter is not available, it is relatively simple to construct the device as shown in Fig.30.

This device is composed of a plug, wires (if necessary, a starting capacitor for compressors which have capacitor starting), and three alligator clips.

Alternatively, a wire plug as included in Danfoss electrical equipment Type 419 can be used instead of alligator clips. A push-button switch is then used to cut in and out the starting winding.

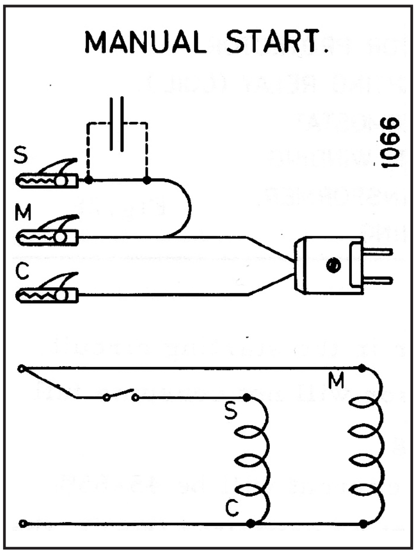

Fig.30

This "device for manual starting" is very useful to the skilled serviceman, but in the hands of an unskilled person it may do more harm than good, because incorrect use offers ample opportunity of burning out the motor.

The device should be used in the following way: The wire plug is connected to the compressor terminal, and a check is made to confirm that the electrical connection is a good one.

The plug is connected to the electric mains, a check being made in advance that the mains supply is energized, and that there is no serious undervoltage.

At the precise moment that the plug is connected to the mains, the run winding of the compressor is energized, and rapid action is therefore necessary.

The push-button switch in the starting circuit is closed at once, and is kept closed for a maximum of 5 seconds. If this period is exceeded, the starting winding may burn out. If starting does not take place, the voltage supply across the run winding will have to be cut off no longer than 10 seconds after circuit has been made.

If the above procedure results in the compressor starting, it can be taken for granted that it itself is in working order. The fault will then have to be sought in the other electrical installations of the refrigerator - e.g. in the starting relay or starting capacitor.

If starting does not take place, the compressor is probably defective.

There may be exceptions, however. Compressors with motors for capacitor starting cannot be expected to start correctly without a starting capacitor.

In such cases, a capacitor of the capacity described should be inserted in the starting circuit. (See Fig.24).

2.3. Locked Rotor.

When the starting torque of a compressor motor is insufficient to overcome the resistance to starting, the condition is denoted "locked rotor". Strictly speaking, the expression "locked rotor" refers to defects in the compressor which hinder its free rotation. In this summary we shall, however, also include other conditions such as, for example, when pressure conditions in the refrigerating system do not allow starting.
The "locked rotor" condition is characterized by the compressor consuming the total starting current.
The starting relay keeps the starting winding cut in, but the rotor does not rotate. Under these conditions, rapid temperature increase may occur in the starting winding, but the motor protector is dimensioned to compensate for such an increase. The motor protector will therefore trip very rapidly (within a few seconds). After the tripping of the protector, some minutes will elapse while the protector bimetal cools down. *)
Then the protector will cut in again, and the starting attempt is repeated. The state of "locked rotor" can be mistaken for other faults, since it often will be difficult to see whether the rotor is stationary or is rotating slowly. The best way to ascertain "locked rotor" is to insert an ammeter with a sufficiently wide range in one lead of the compressor. If the compressor consumes the total motor starting current, a "locked rotor" can be diagnosed.
If the system is also equipped with pressure gauges, it can be noted that pressure fluctations do not occur. This in itself, however, is no indication of "locked rotor", as the same result will occur when unsuccessful starting is due to breaks in the starting circuit.

LOCKED ROTOR.

INDICATED BY:
INSUFFICIENT STARTING TORQUE.
CUT IN START WINDING.
FULL STARTING CURRENT CONSUMED BY COMPRESSOR.
NO ROTATION OF COMPRESSOR.
TRIPPING OF MOTOR PROTECTOR.

CAUSES:
MECHANICAL LOCKING.
CONDITIONS IN SYSTEM (EQUALIZING ETC.)
UNDER - VOLTAGE.

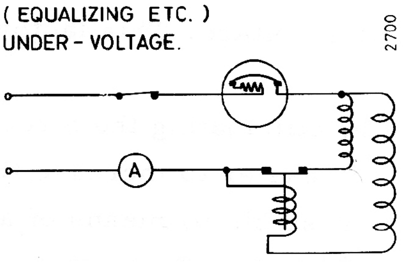

Fig.31

The causes of "locked rotor" can be grouped under three main headings, viz.:

a) Mechanical locking
b) Conditions prevailing in the system
c) Undervoltage

a) As previously mentioned, "locked rotor" may be due to the fact that the rotor is literally locked. If a compressor or a refrigerator is subjected to severe transport conditions (being dropped, knocked, etc.), the stator or the cylinder may - in the worst case - be actually knocked out of position, so that the rotor or piston is locked.

b) The most frequent cause of "locked rotor" is incomplete pressure equalizing in LST refrigerating systems.

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*) Concerning built—in motor protectors, the cut-in time is considerably longer.

As previously mentioned, compressors with a low starting torque are most frequently used in capillary-tube refrigerating systems. A condition for LST compressors being used is that the compressor starts only when the pressure on the high side and suction side has been completely, or almost, equalized. This means that the compressor control has to be adapted so that there is always a standstill period long enough for pressure equalizing to occur. In most refrigerators, this equalizing period is about 5 minutes. In freezers, the equalizing period is somewhat longer (generally 8 - 12 minutes).

Tripping of the motor protector due to incomplete pressure equalizing in a refrigerating system may be quite harmless. Tripping may be caused, for example, by I cutting out the compressor, and restarting it immediately afterwards. If a period of 5 minutes is allowed to elapse for pressure equalizing to occur, starting will take place correctly.

On the other hand, there is reason to take note of instances of frequent or regular protector tripping, as for example whenever the thermostat is cut in, because sooner or later this will destroy the protector and perhaps also the starting winding. In cases of conflict between the thermostat "off" -time and the system equalizing time, this may be due to faulty design. The following errors may occur:

1) Too small a thermostat differential has been selected. For normally dimensioned refrigerating systems, generally thermostat differentials of 8-10°C~14°-18°F for refrigerators and 6°-8°C~11°-14°F for freezers will prevent difficulties.

2) The system may be incorrectly dimensioned, so that evaporation has to take place in "liquid pockets" before equalizing can occur. Typical examples of this are incorrect piping in the condenser or incorrect location of the liquid line drier. Other important factors are the capillary tube dimensions, or complete or partial blocking of this tube.
   We shall further examine these faults in the section of system faults.

3) The thermostat bulb may be fitted so badly that the standstill period becomes unexpectedly short. Errors of this type are frequent. In the section of system faults we shall give details of the correct bulb position.

c) "Locked rotor" may also be due to extremely low starting voltage.
This factor will be further dealt with in the subsequent section.

In general, the "locked rotor" condition can be remedied by eliminating the direct cause. But this may be troublesome, and in many cases it is easier to increase the compressor starting torque. For LST compressors this is possible by means of a starting capacitor as described in section 1.

2.4. Undervoltage.

Electric motors are of course dimensioned for use over a definite voltage interval. If this voltage interval is too small, the motor cannot be expected to operate efficiently.

Undervoltage problems are encountered in all parts of the world. The simplest form of undervoltage may be the result of the consumer living far from the nearest transformer. More annoying forms may be due to greatly underdimensioned power stations, distribution mains and house installations.

The latter examples occur particularly in countries which are technically underdeveloped. In such areas, fluctuating voltages and large voltage drops during starting are not uncommon. Supply mains will often be characterized by current consumption which is so low during certain periods (e.g. at night) that consumption points are subjected to high overvoltage. Of course, this does not make matters any better.

As previously mentioned, the torques supplied by a motor depend on the terminal voltages available. This means that the starting torque, the breakdown torque, and other torques will be reduced when the voltage drops.

Motor torques vary according to the following formula:

$$\frac{M_2}{M_1} = \left(\frac{U_2}{U_1}\right)^2$$

Thus, at 85% of the rated voltage the torques will amount to approx. 73% of their values for the rated voltage.

Graphically, the relation between voltages can be expressed as shown in Fig.32.

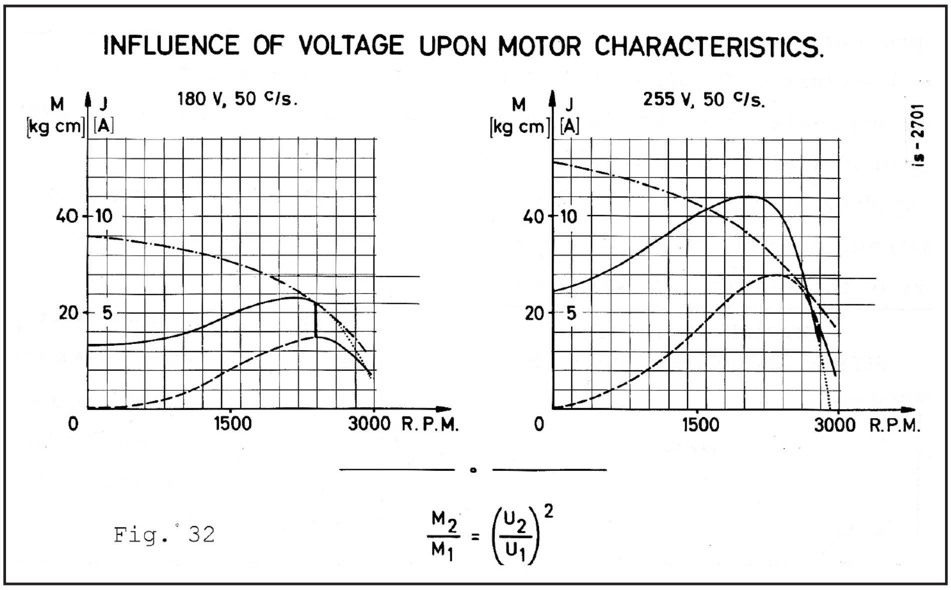


Fig. 32

It is obvious that a hermetic compressor cannot operate at a given undervoltage if the torque requirements exceed the torques available.

It may be mentioned, incidentally, that not only the voltage but also the mains frequency affects the torques produced. This effect cannot be simply evaluated. As an approximation it will vary between the inverse proportion of the frequencies and the square of this ratio:

$$M_1 \cdot \frac{f_1}{f_2} > M_2 > M_1 \cdot \left(\frac{f_1}{f_2}\right)^2$$

Provided the voltage is stable, an increase of mains frequency will result in a reduction of the motor starting and breakdown torques. This should be borne in mind when refrigerators designed for 50 Hz (c/s) are exported to countries using 60 Hz (c/s).

Very often the effect of frequency variability on the starting and operating conditions of refrigerators is smaller than specified above. This is because the rated voltages of 50 Hz and 60 Hz mains are seldom identical. For example, the alternative voltage for 220V 50 Hz is often 230V 6OHz (l10V 50 Hz - 115 V 60 Hz).

The above "weakening" of the motor - no matter whether it is caused by undervoltage or increased mains frequency - will, of course, be primarily experienced when the torque requirements from the system are at a maximum. Such conditions may occur at the moment of starting, immediately after starting, and also - in certain circumstances - during operation.

In what follows the most important factors will be dealt with in the same order.

2. 41 Effects on the Starting Torque Requirement.

It is generally true to say that the size of the starting torque is important only during compressor starting, to overcome the resistance to rotation. In systems with a capillary tube and sufficient time for pressure equalizing the starting torque itself is, therefore, very seldom critical. But if the situation arises where attempt are made to start an LST compressor with a pressure difference between the suction and delivery sides, conditions may very well become critical, and the troubles will increase in proportion to the suction side pressure. Fig. 33 shows an example of pressure condition effects on the starting properties of a PEEWEE compressor. It also applies incidentally to HST compressors that their starting properties may be impaired, not only by an increased pressure differential, but also by the absolute size of the suction side pressure.

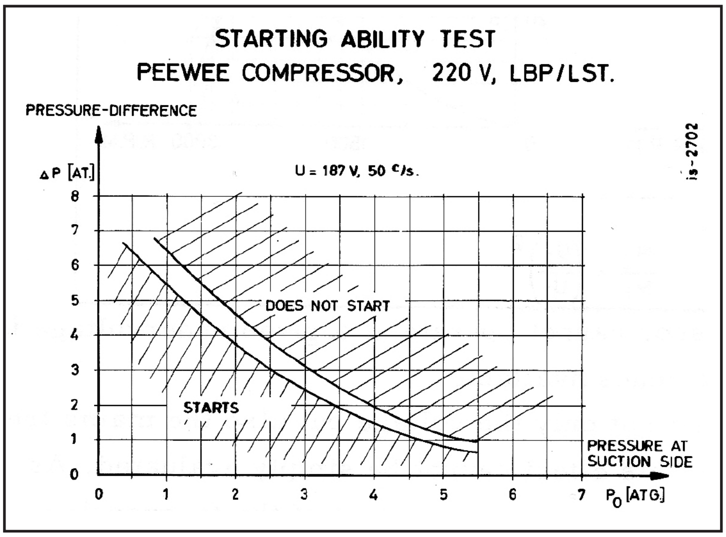


Fig.33

In systems with capillary tube injection, the same pressure will often exist on the suction and delivery sides at the moment of starting. This pressure is then termed "equalizing pressure" and is at a maximum when both the evaporator and compressor are " hot". This is seldom the case in practice, but one example is the starting process after forced defrosting of the evaporator.

If defrosting is done by electric heaters, for example, the compressor will start when it is relatively hot and the equalizing pressure approximates to the pressure of the saturated vapours at the evaporator surface temperature.

In other systems with capillary tube injection but without forced defrosting, the highest equalizing pressure will occur in practice when the entire system has been temperature-equalized to the maximum ambient temperature. In systems with a relatively large refrigerant charge, substantially higher equalizing pressures may occur under these conditions than after the defrosting conditions mentioned above. The maximum permissible equalizing pressure depends to some extent on the compressor type, but in particular on the desired size of the undervoltage range. A guiding rule is, however, that the equalizing pressure at maximum ambient temperature should never exceed 5 atm. g~71 psig when the compressor is of the LBP or LBP/MBP type. For the sake of completeness it should be added that it is much more important to observe this limit on account of the breakdown torque than on account of the starting torque. (See 2.42). That the starting sequence of the compressor can be critical at undervoltage is largely due to the starting voltage being always lower than the operating voltage, and the starting torque being correspondingly smaller. Fig.34 shows a schematic representation of the start-up sequence. Before the compressor is started, the mains voltage is U_1 (unloaded mains voltage). At the moment of starting the motor consumes the starting current, also called the "locked rotor" current. A considerable voltage drop then takes place, and the real starting voltage is therefore U_2 only.

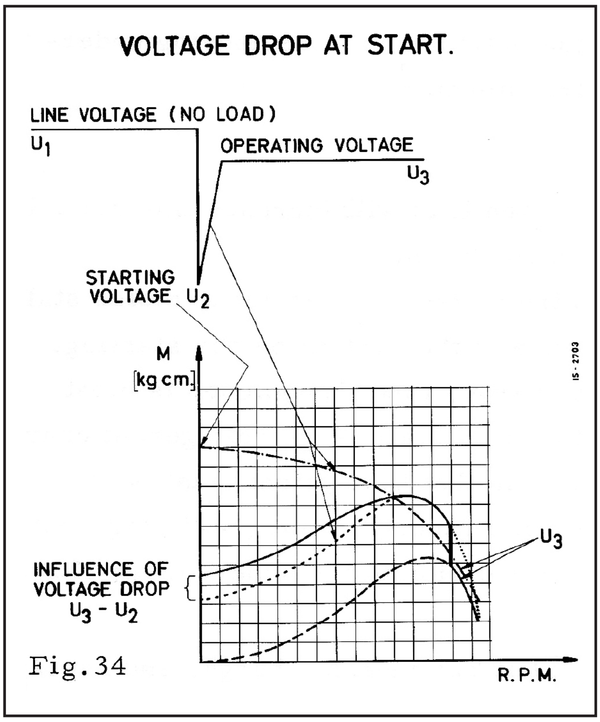


Fig.34

The voltage drop at the moment of starting depends largely on the actual mains installation, i.e. the voltage drop will be especially large in the case of so-called "weak mains".

As the motor accelerates, the current consumption drops. When the start winding is then cut out, the voltage will be somewhat higher. This voltage, U_3 in Fig.34, is called the "operating voltage".

It should be mentioned in this context that when starting problems are encountered with compressors and refrigerators, it is the concept of minimum starting voltage which is of interest, i.e. the voltage (U_2) at the moment of starting.

It is of little use therefore to deal with the "unloaded mains voltage" U_1 or with the operating voltage U_3. On the other hand, the terminal voltage U_2 is decisive for the compressor at the moment of starting.

When starting is correct the terminal voltage at the moment of starting cannot be recorded on a normal voltmeter. This is possible, however, with unsuccessful starting, i.e. when the motor consumes "locked rotor" current for some time. Starting troubles originating from undervoltage can be eliminated by increasing the torques given off in the motor. This can be done by reducing the voltage drop during the starting sequence or by a general increase of the starting and accelerating torques.

For these reasons, the starting capacitor provides a convenient possibility for remedying starting troubles. This is partly due to the fact that it can limit the starting current and, hence, the reduction of the starting torque originating from the voltage drop during starting, and partly to the fact that a starting capacitor can directly increase the starting torque at a given voltage.

(For the application, where necessary, of starting capacitors on PEEWEE compressors with LST motors, see section 1: Starting Capacitor).

Another way to avoid starting troubles is, of course, to use a pretransformer. In very weak mains the situation can, however, easily be such that the ratio of conversion has to be chosen so high that there is a risk of abnormal overloading during operation when relative overvoltage prevails on the primary side of the transformer.

Conditions determining the selection of a pretransformer have also previously been described: See section 1; Transformer. In the case of HST compressors, which are already equipped with a starting capacitor, the only means of remedying undervoltage problems will be by the use of a pretransformer.

2.42 Peak Load immediately after Start.

In refrigerating systems with a capillary tube, the load will increase immediately after starting from the temperature-equalized condition.

This peak load, which, if the worst comes to the worst, may result in motor stalling, varies directly with the equalizing pressure in the system before starting. Since the equalizing pressure depends on the charge, this phenomenon is most likely to give rise to troubles in systems with a relatively large refrigerant charge. To avoid this, the guiding rule in this case also is that the system must be designed so that the maximum equalizing pressure does not exceed 5 atm.g~71 psig. But this rule will, of course, become more stringent in relation to the undervoltage range desired.

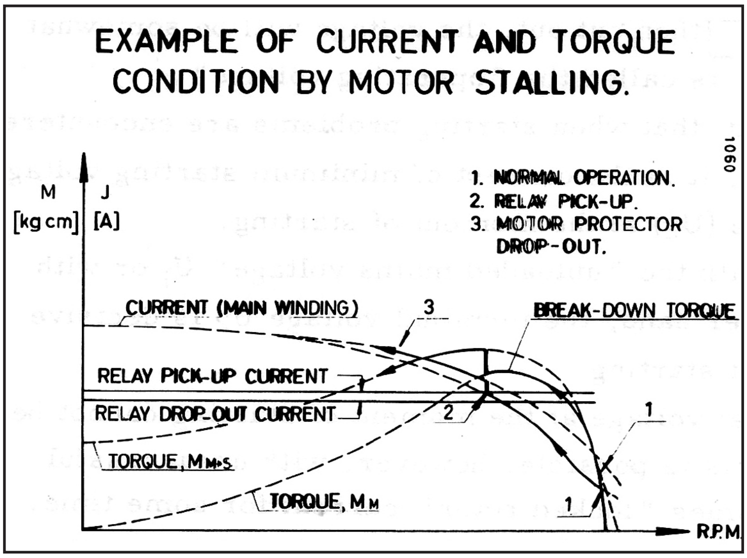


Fig.35

The refrigerant charge, and hence the equalizing pressure, in systems with capillary tube control can be reduced by keeping the internal evaporator volume as low as possible. Consequently, it will not be of particular advantage to use large pipe dimensions in a freezer. Motor stalling immediately after start may occur as suggested in Fig.35. The motor accelerates and in some instances the start winding is not cut out. In other cases it is cut out, but shortly after the current is increased, the starting relay cuts in again, and the motor protector begins to operate.

The above undesirable effect on a given system can be put right in one way only by increasing the breakdown torque available. On a given compressor this is only possible by increasing the voltage, i. e. by installing a pretransformer.

2.43 Motor Stalling during Operation.

As the load on a compressor is increased proportionately to the evaporating temperature, circumstances may be foreseen where the breakdown torque available at undervoltage will also be insufficient during operation.

Such large loads may occur when the ingress of heat is very large. In refrigerators and freezers it is the conditions of cooling, freezing, and ice freezing which must be considered, since under these conditions relatively high evaporating temperatures — and also high condensing pressures may be experienced. Motor stalling in these circumstances will be shown by an increasing current consumption until the start winding is cut in again, and the motor protector comes into operation.

As the load condition may prevail over a lengthy period, and as prior to loading the motor may be warm due to operating (e.g. freezing or ice freezing), this overload will also result in a relatively high temperature on the motor windings. If the system conditions cannot be altered, and this is seldom possible in practice, "motor stalling during operation" can only be avoided by increasing the breakdown torque, i.e. by using a pretransformer.

2.44 Starting Problems at Low Ambient Temperatures.

When hermetic compressors and hermetic refrigerating systems are exposed to very low ambient temperatures, different problems of a special nature may arise. These special problems can be referred to the fact that during the abnormal cooling of a compressor, conditions are created for which the motor is not dimensioned.

Since the motor - as already mentioned - is weakest at undervoltage, the problems suggested will, of course, identify themselves in practice under conditions of low voltage.

In what follows, the types of problem which may arise are described.

The viscosity of an oil depends on the temperature - the warmer the oil, the thinner will it be.

The relationship between temperature and viscosity is expressed by the so-called viscosity index.

As in many other applications, it is desirable that hermetic compressors should use an oil, the viscosity of which varies as little as possible with temperature. On the other hand, the alternatives available are limited if it is desired to avoid the use of additives in order to preserve chemical stability.

Fig.36 shows the relationship between temperature and viscosity for some compressor oils.

When used in a refrigerating system, the compressor oil will not be pure but more or less mixed with the refrigerant.

The larger the amount of refrigerant which is mixed with a given volume of oil, the lower will the viscosity of the mixture be. On the other hand, the ability of the oil to absorb refrigerant depends very largely on temperature and pressure.

Fig.37 shows the relation between temperature and viscosity for a refrigerating machine oil mixed with different amounts of R12.

When choosing an oil for a compressor type, various methods of testing are applied, and different sets of conditions considered.

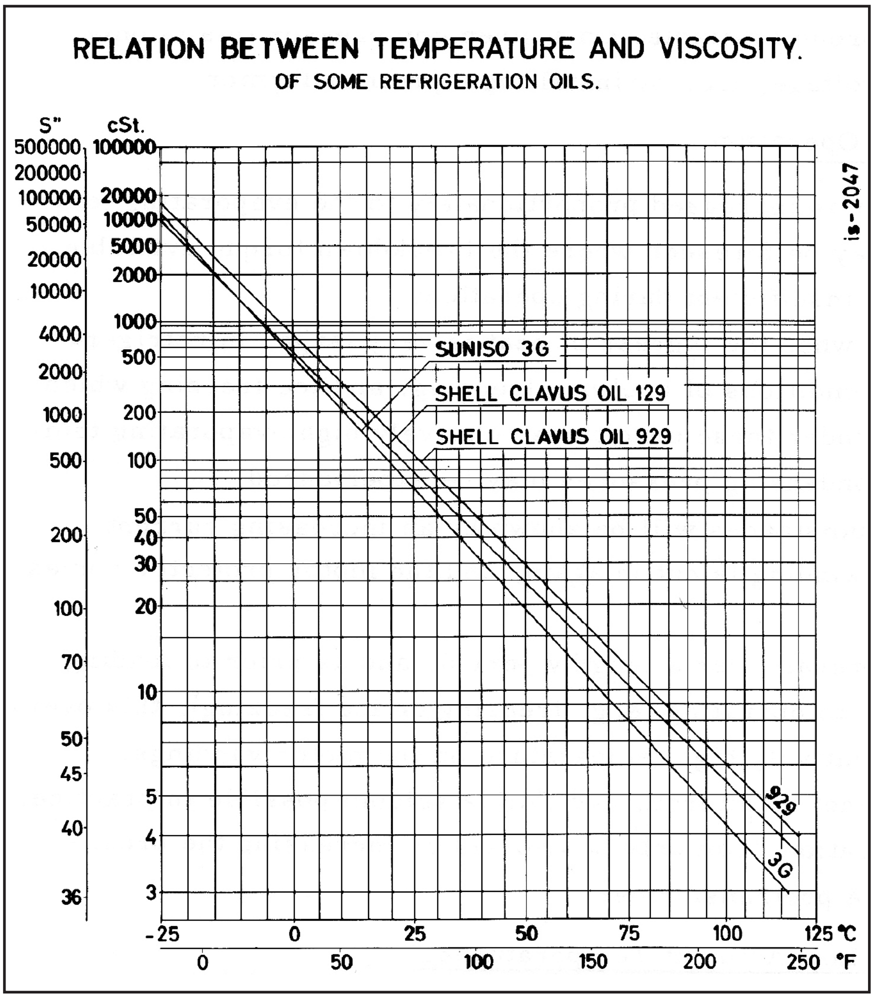


Fig.36

As regards lubrication, it is obvious that the oil must be chosen so that effective lubrication is ensured under the widely different operating conditions to which the compressor may be exposed. In this respect, the operating conditions resulting in a large load are most critical, since the internal temperature of the compressor then increases sharply. In these circumstances, the oil temperature will be high and the viscosity will be low. It is logical for the correct compressor oil to be chosen so that even under the most rigid operating conditions an oil film is ensured between the piston and the

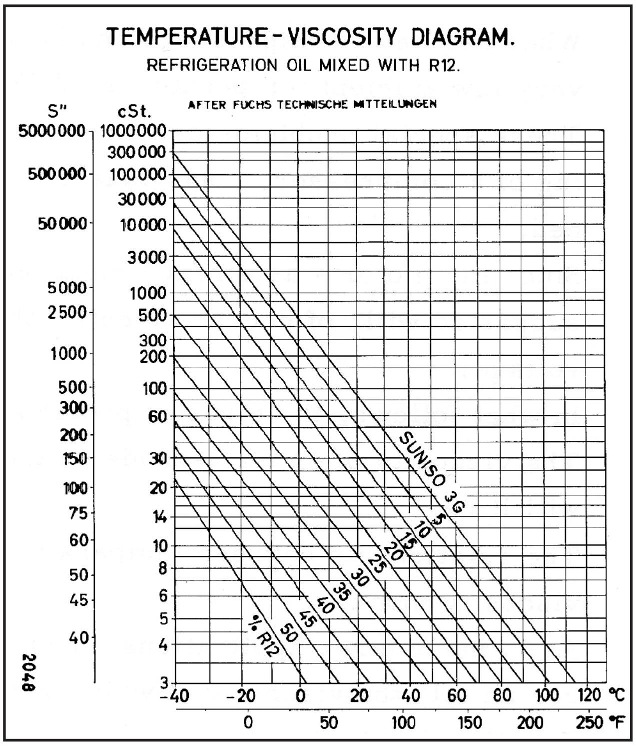


Fig.37

cylinder and in the bearings, this oil film having adequate supporting capacity. Such conditions can be ensured only by allowing a relatively high viscosity to prevail at low temperatures. Under certain circumstances this may be disadvantage, but it need not present major problems, especially if the increased viscosity effects on the compressor are known in advance. The disadvantages due to compressor oil viscosity will occur during starting and be caused by the friction in the compressor bearings, which increases proportionately to the viscosity. Since PEEWEE compressors are all constructed according to the same principle, the friction in the bearings is therefore almost identical for all sizes of these compressors, provided the oil viscosity is the same.

There is, however, a great difference between the torques of the different motor sizes, and it is therefore natural that the compressors with the smallest motor sizes should be in a worse relative position than those with larger motors. The result is that, in practice, the compressor oil viscosity only affects the starting properties of our smallest compressors. When a compressor is started in the normal way, and at normal ambient temperature, the oil pump starts operating very rapidly, and the oil in the bearings will soon be replaced by oil from the compressor oil sump. This oil will contain refrigerant. The ratio of mixture is determined by the prevalent temperatures and the refrigerant pressure on the oil surface. (See Fig.38).

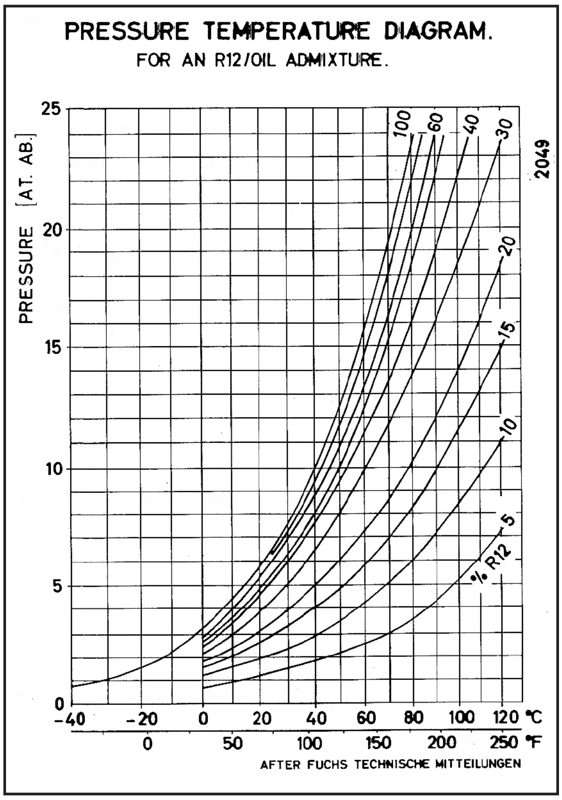


Fig.38

The presence of refrigerant in the oil naturally causes the viscosity to decrease. While the compressor is operating, its temperature will increase together with the temperature in the bearings and oil. As the temperature of the oil flowing through the bearings gradually increases the ability of the oil to hold refrigerant is reduced. The oil remaining in the bearings at the moment a hot compressor is stopped, will therefore be relatively poor in refrigerant content.

As there is no close relationship between the refrigerant in the system and the oil film in the bearings, it is to be expected that the oil film will still be poor in refrigerant the next time the compressor is started. Should it then happen that the ambient temperature of the refrigerator is substantially reduced, the oil temperature will also fall, provided the compressor is not operating. In this way, the viscosity of the oil which is poor in refrigerant in the bearings is increased, and the potential friction increases proportionately.

When the compressor is restarted under these conditions, a correct starting sequence will depend on the starting torque of the motor. If the condition is critical, the compressor will either not start at all, or the rotor will only rotate slowly until the overload protector trips.

The protector has therefore stopped the motor before the compressor oil pump has started pumping, and the oil which is poor in refrigerant in the bearings has not been replaced by oil of a lower viscosity which is mixed with refrigerant.

The unsuccessful start causes heat to accumulate in the motor and compressor. In borderline cases, this accumulation of heat may be sufficient for the starting sequence to be correct when the protector cuts in again. In more serious cases, the protector may trip several times before correct starting occurs. Since,however, the protector is dimensioned to prevent critical temperatures in the motor windings, the starting sequence described need not give rise to any fear of permanent damage.

The conditions above relate to cases where refrigerator is out of operation for some time, while the ambient temperature is low. The problems may occur on PW3K6 at about 12°C~54°F, and lower temperatures. In the case of larger motors the problems arise only at lower temperatures.

When the compressor of a refrigerating system is stopped, absorption of refrigerant in the compressor oil takes place during the subsequent pressure equalizing. If the temperature of the compressor is low, and if at the same time the total refrigerant charge is relatively large, oil may be expected to mix with relatively large amounts of refrigerant so that the oil level is raised. The result is that during compressor restarting the refrigerant will prime strongly due to the rapid pressure drop in the compressor housing, so that oil hammer may occur and the compressor housing will be more or less filled with oil-refrigerant foam. The oil/refrigerant mixture may reach the rotor and enter the motor air slot so that acceleration is impeded. This may cause the current and watt consumption to fluctuate for a while, but this fluctuation will only be noticed with our smallest compressors. On the whole this condition gives rise to no disadvantages, and generally it is not even noticed.

It follows, on the other hand, that these conditions are noticed on all small compressors with the motor suspended upside down, irrespective of make. Starting troubles which originate from the influence of the viscosity on the bearing friction may also occur when a cold compressor is started without the presence of refrigerant. For example, a compressor may be transferred directly from a cold store -perhaps an outdoor store- to the point of application. The problem may then occur in conjunction with starting-up the compressor during the filling-in of refrigerant. In the latter case it is a rule general that the compressor should not be started until the vacuum created during the evacuation has been equalized by refrigerant gas. However, it is not to be expected that the oil film in the bearings will be mixed with refrigerant. The bearing friction will, therefore, in this case also be determined by the viscosity of the oil film which is present in the bearings from the previous operating period, which is normally the trial run by the compressor manufacturer.

Correspondingly -as described for compressors started in systems with a refrigerant charge- it applies also to compressors only that the models having the smallest motors may give rise to problems. Any difficulties can, of course, be avoided by storing the compressors at normal room temperature for some time before they are put into service. Another much used procedure is to do the initial starting at an overvoltage of e.g. 10%. We already have noted that the torques evolved by the motor increase with the voltage, and the lowest voltages will therefore be the most critical.

If all precautions are omitted, the result is merely a number of protector trips provided the compressor is correctly fitted with electrical equipment, and starting will then proceed correctly. On the other hand it may be dangerous to try to start up the compressor without a protector, since in that case there is no protection against critical temperatures on the motor windings, and the result may be burning out of the motor.

2.5 The Overload Protector trips during Operation.

This category of troubles includes the cases where the compressor is unduly cut out by the overload protector during continuous operation. On the other hand, starting is assumed to take place without difficulty.

Even though a protector trip is assumed to be an expression of abnormal operating conditions, it should be realized that many refrigerating units are regularly subjected to peak loads. In a refrigerator this may happen, for example, during cooling or freezing of ice. Single trips under these conditions do not necessarily imply any fault. On the other hand,there is every reason to interfere when tripping is recurrent and frequent, so that the cooling function is unsatisfactory.

As previously mentioned, an external overload protector is made to trip by a combined current and thermal effect. It can therefore be understood that operating conditions which are related to a large current absorption and a high compressor temperature are especially liable to result in tripping of the overload protector.

Fig.39 shows the influence of different external effects on winding temperature and current absorption.

From Fig.39 the important elements can be summarized as follows:

2.51) Very high voltage
2.52) High condensing pressure, high ambient temperature, bad ventilation.
2.53) Abnormal evaporating temperature.
2.54) Other conditions.

INFLUENCE ON WINDING TEMPERATURE AND CURRENT.

	WINDING TEMPERATURE	CURRENT
OVER-VOLTAGE	+	+
EXTREME UNDER-VOLTAGE (BREAK DOWN)	+	+
AMBIENT TEMPERATURE	+	+*
CONDITION OF VENTILATION	+	+*
CONDENSING PRESSURE	+	+
LOW EVAPORATING TEMPERATURE	+	
HIGH EVAPORATING TEMPERATURE		+

*BECAUSE OF RISE IN CONDENSING PRESSURE.

2705

Fig.39

2.51 Very High Voltage.

It will have been seen from Fig.39 that high voltage raises both the motor temperature and current consumption.

It is therefore obvious that a high overvoltage may result in protector trips. This trouble can be remedied most effectively by fitting a pretransformer. Furthermore, it will often be advantageous where extreme overvoltage may be expected to take precautions beforehand by improving the temperature conditions of the compressor by the use of oil cooling or fan cooling, if required. The warmer the working climate of the compressor, the more necessary will these precautions become.

2.52 High Ambient Temperature, Bad Ventilation, High Condensing Pressure.

The higher the ambient temperature in which a compressor has to operate, the greater the risk of protector trips. Not only is the ambient temperature of the refrigerator decisive, but also to an equally high degree the ventilating conditions determining the ambient temperature of the compressor. If ventilating conditions are thought to be bad, it will always be wise to measure the ambient air temperature at the compressor and condenser proper.

The above conditions will generally be critical only at extreme ambient temperatures. If it is not a question of a directly incorrect position of the refrigerator, such troubles can be eliminated only through alterations of the design, i.e. by changing the possibilities of ventilation in the machine compartment of the refrigerator, by mounting a fan or by using a compressor with an oil cooling device.

A high ambient temperature will normally also have a bad effect on the condensing pressure. Hence, the possibility of protector trips will further increase since the increased condensing pressure leads not only to increased compressor temperature but also to higher current consumption.

A high condensing pressure need not always be exclusively a design problem.

It may also be due to other factors. For example, a classical example is contamination of the condenser, resulting in reduction of the heat transfer coefficient. This condition especially occurs in the case of fan-cooled finned condensers. There are other possibilities: a defective fan, overcharging of the system, and the presence of large amounts of non-condensable gases (atmospheric air, nitrogen, etc.).

A high ambient temperature may also affect the operating conditions of the compressor by increasing the evaporating temperature because of the increased heat transfer from the ambient air, so that the load and, as a result, the current consumption are increased.

2.53 The Influence of the Evaporating Temperature.

Under operating conditions with low evaporating temperatures, the current consumption is also low. Such conditions therefore seldom cause protector trips. At a high evaporating temperature the compressor load and, hence, the current consumption are increased. On the other hand, the cooling of the motor is improved because of the increased gas density, at any rate at normal voltage and at higher evaporating temperatures.

If the evaporating temperature tends to increase the frequency of protector trips, this will mainly occur in cases where a compressor is used outside its recommended range, e.g. when an LBP compressor is used in the HBP range. The frequency of protector trips will then increase when the voltage drops.

2.54 Other Conditions.

Protector trips can, of course, also be caused by a number of qualitative faults, of which a few are mentioned below.

If by mistake the compressor has been equipped with a protector with a lower trip current than prescribed, difficulties may easily arise. If protector difficulties do occur, a check should always be made that the protector used corresponds to the type prescribed by the compressor manufacturer.

If a starting relay with an incorrect pick-up current is used, there is a risk when the load increases that the relay will cut in during operation, resulting in protector tripping. In practice, such a fault will generally have already shown up during starting. In addition, it is of course also true to say that any compressor defect increasing the current consumption may help to make the protector trip.

3. Refrigerating System.

In this section we shall deal with operating conditions and typical troubles in refrigerating systems. The section deals mainly with refrigerating systems in which capillary tubing is used as metering device.

3.1 Circuit.

Hermetic refrigerating systems consist of the same main components as other refrigerating systems, i.e. compressor, condenser, evaporator, metering device, and drier. However, if capillary tubing is used for metering, there is then a fundamental difference, since such systems never have a receiver. The refrigerant undergoes the same changes of state as in other compressor refrigerating plants. In an ln p-enthalpy diagram the cyclic process will therefore be as shown in Fig. 40.
The capillary tube is generally soldered to the suction line, so that a heat exchanger is formed. There may, therefore, be a change in the enthalpy during the pressure reduction in the capillary tube, as indicated by the dotted line in Fig. 40.
The advantage accruing to the refrigerating plant by this arrangement is somewhat doubtful. On the other hand, it does serve a number of practical purposes.

THE REFRIGERATION CYCLE.

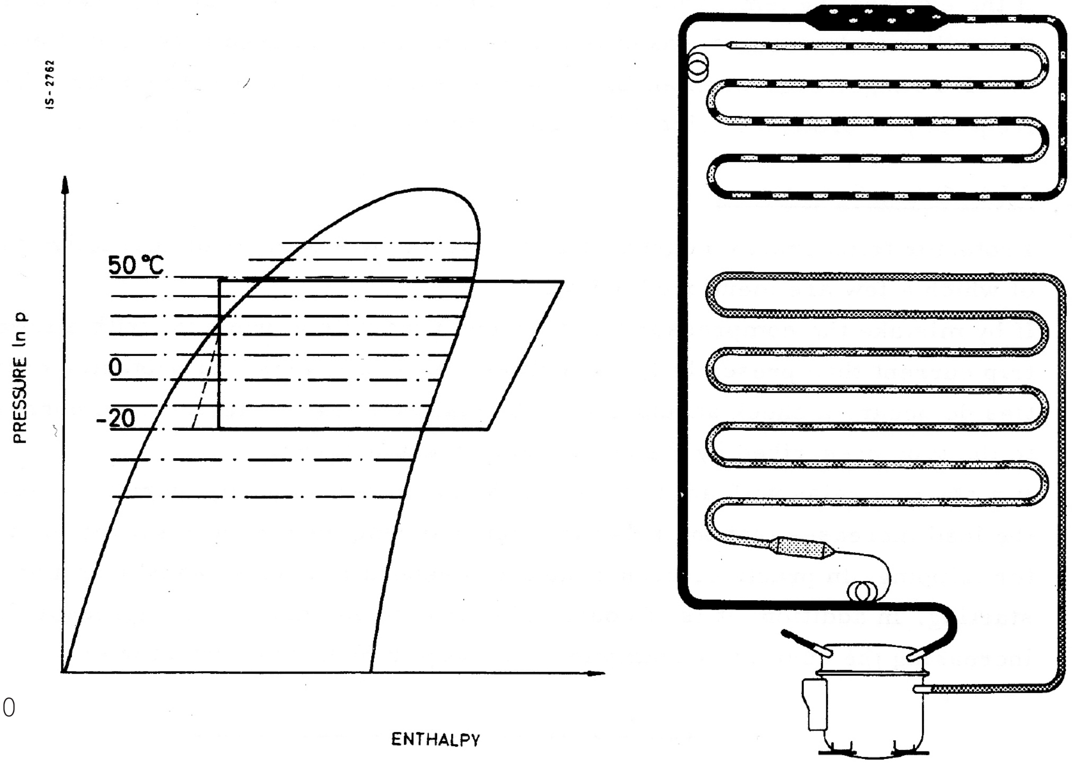


Fig.40

Refrigerating systems using capillary tubing as a metering device can only be balanced for optimum utilization within relatively narrow operating conditions. This is partly due to the way the capillary tube operates, and partly to the fact that the refrigerant charge is critical, depending on operating conditions, among other factors.

The interrelation between the components is shown diagrammatically in Fig. 41. It will be seen that the quantity of flow through the capillary tube is affected by the conditions at the inlet and outlet, i.e. the condensing pressure and evaporating pressure, among others. Conversely, the resistance in the capillary tube affects the evaporator and condenser conditions.

The conditions in the evaporator are also affected by the compressor capacity and the total charge of the system.

In the same way, the condensing pressure is affected by the compressor capacity, capillary tube resistance, amount of charge, and ambient temperature. As regards the compressor, the refrigerating capacity will adjust itself depending on the conditions at the evaporator and condenser.

It is therefore evident that a balanced system is involved which can very easily become unbalanced when the characteristics of the individual components are altered. Irregularities in the refrigerating circuit are evidenced, first and foremost, by pressure and temperature variations in the evaporator and condenser.

Diagnoses of system faults are therefore most reliably made on the basis of pressures and temperatures in evaporator and condenser.

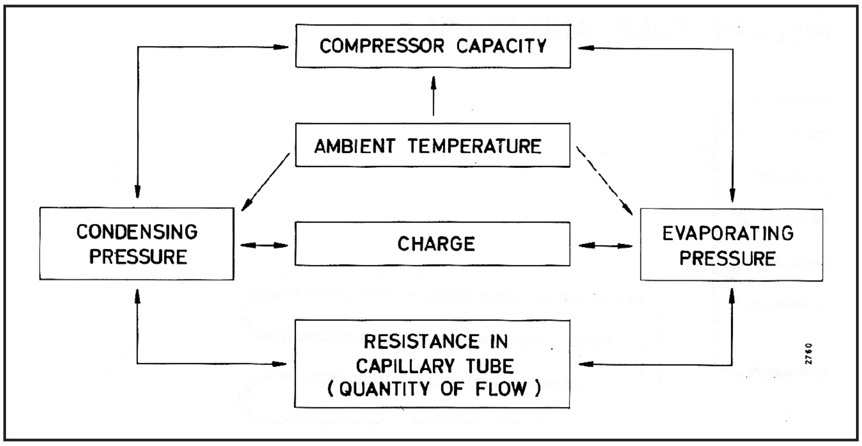


Fig.41

The most important auxiliary equipment for the serviceman during fault location consequently comprises pressure gauges and instruments, which if required can measure the surface temperature.

The pressure gauge is a classic auxiliary device for fault location in refrigerating plants. For it to be used on a hermetic refrigerating system, it is, however, necessary for the system to be opened, and the so—called "service valves" are used for this purpose.

If the serviceman is suitably equipped, pressure gauging may often be replaced by temperature measurements, so that interference with the system is avoided.

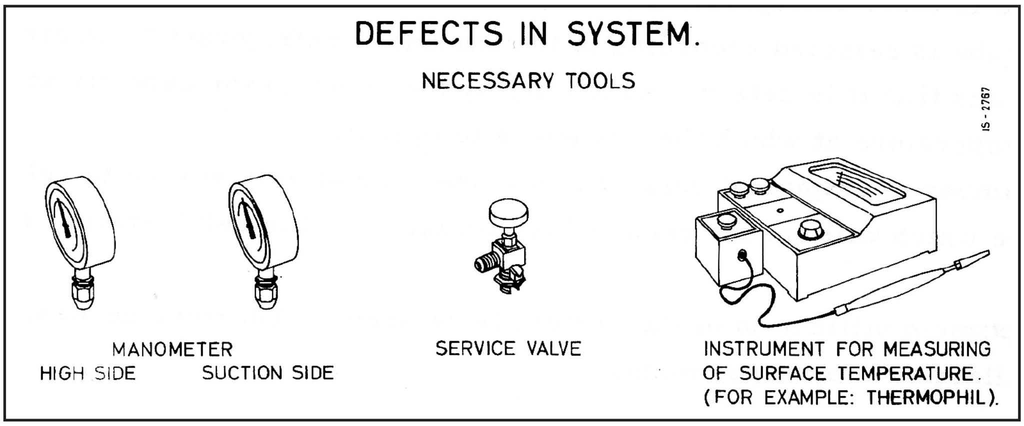


Fig.42

In a correctly balanced refrigerating system, refrigerant conditions occur as shown in Fig. 43. The compressor draws in gas at suction side pressure; this gas will generally be superheated to the ambient temperature.
At the condenser inlet, the gas temperature is rather high. In the central section of the condenser condensation takes place, and the temperature is always constant at this point.
There is generally liquid present in the lowest tube of the compressor. At the capillary tube inlet, the refrigerant will be slightly sub-cooled.
If the system is correctly charged, most of the evaporator will have temperatures corresponding to the evaporating pressure. For practical reasons, optimum utilization of the evaporator is often dispensed with. In that case, a slight superheat will occur at the evaporator discharge.

CONDITIONS OF SYSTEM WITH PROPER
CAPILLARY TUBE AND CHARGE.

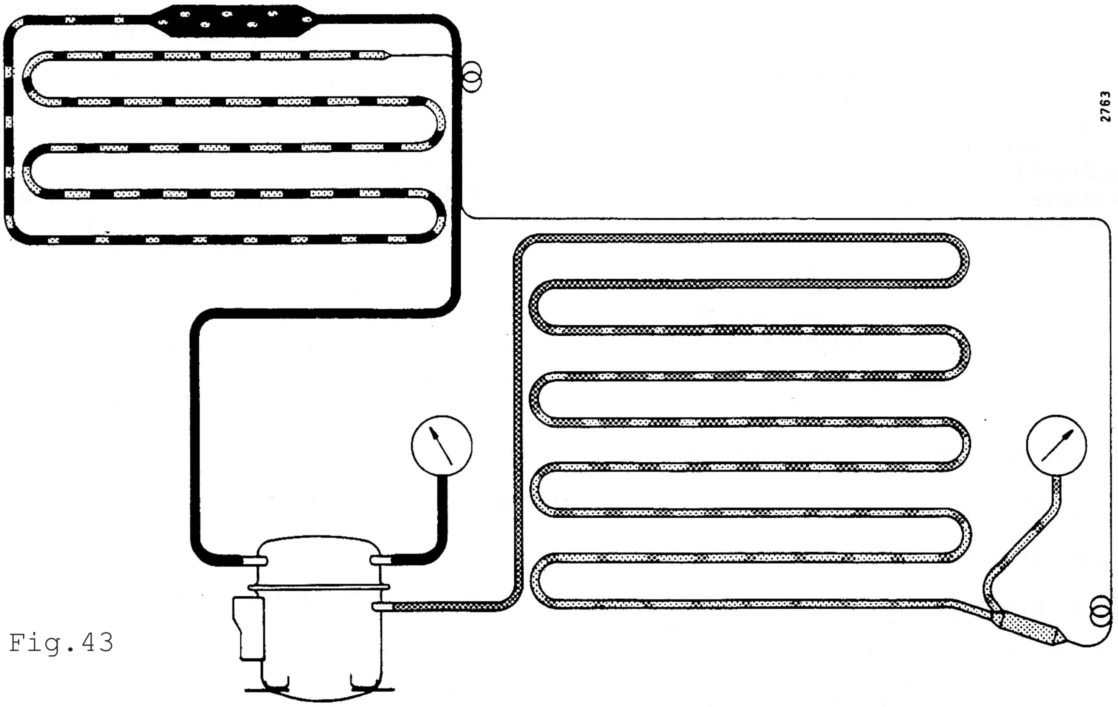


Fig.43

3.2 The Capillary Tube.

In hermetic refrigerating systems, the capillary tube assumes the function of the expansion valve in other refrigerating plants.
The capillary tube is selected according to the amount of refrigerant to be circulated. This means that it is determined mainly by the compressor capacity at the evaporating temperature at which the system is to operate.
There are a number of empirical rules which make it relatively simple to select a capillary tube which will ensure reasonable utilization of the refrigerating system involved.
However, if optimum utilization of the system is desired, it becomes necessary to select the capillary tube by experiments.

The liquid flow through the capillary tube is determined by the internal resistance, which is itself controlled by the length and internal diameter. There is, therefore, often the choice between a tube with relatively small internal diameter and short length and tubes with a larger internal diameter and greater length. It will be an advantage to select - within reasonable limits - the capillary tube which has the largest internal diameter, since such a tube is less liable to be obstructed.
A good rule to bear in mind is that the internal diameter of the capillary tube should never be less than 0.6 mm.
As mentioned previously, the equilibrium in the refrigerating system is upset when the flow resistance in the capillary tube is altered.
If the capillary tube is partially obstructed, e.g. by a dirt particle, the capillary tube resistance is increased and the flow is reduced. Put simply, the result is that refrigerant has to be transferred from the evaporator to the condenser until a new equilibrium is achieved. This means that the system operates at an increased condensing pressure, and a greater proportion of the condenser is filled with liquid. The evaporator will be short of refrigerant, and this will be evidenced by reduced utilization, since superheat will now occur over an increased proportion of the surface. If the obstruction of the capillary tube is very pronounced, the suction side pressure will also fall.
The practical result of partial obstruction will always be a reduction in the refrigerating capacity, which again means that the normal temperatures cannot be obtained in the refrigerating unit. As a superficial judgment, it may be decided that the trouble is due to "loss of charge". If, however, the condensing pressure is watched, especially in connection with the refilling, if necessary, of the system, the true explanation will soon emerge. In obstructed systems, the refrigerant will, to a great extent, be transmitted to the condenser, where it will remain as sub-cooled liquid in the lowermost tubes. If the appropriate instruments are available, it will therefore be possible to determine the nature of the trouble by measuring the surface temperatures.

Since an increase in the condensing pressure affects the power consumption, it might be expected that measurement of the current and wattage consumptions would give an indication of the cause of the trouble. This cannot be entirely relied upon since, as already mentioned, clogging-up may result in a drop in the suction side pressure, and it is therefore not certain that the current and wattage consumptions will increase.
In the example given above, we have considered a case where the resistance in the capillary tube is increased by the presence of foreign matter. In principle, the result will be the same if the increased resistance is caused by using an incorrectly dimensioned capillary tube, as when the internal diameter is too small.

Increased resistance in capillary tubes may be due to many factors including particles from insufficiently cleaned system components, or dust particles from low quality driers. But the capillary tube can also be maltreated during the mounting process, thus creating the basis of subsequent complete or partial obstruction. This may be the case when the inlet cross-section is altered by crimping or squeezing the tube. This makes it more probably that small particles will be retained, resulting in obstruction of the capillary.

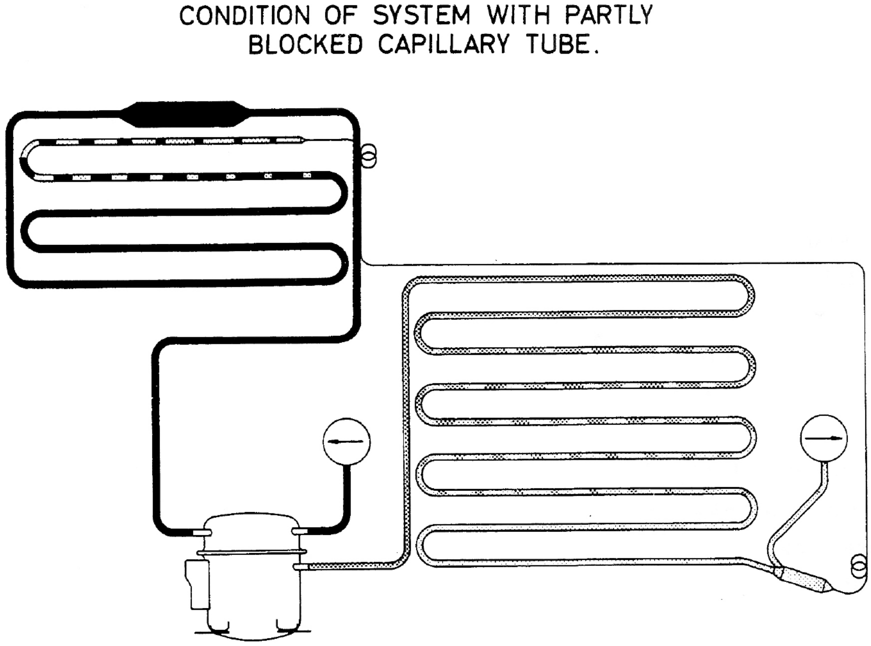


Fig.44

Partial obstruction, as well as other conditions increasing the condensing pressure, has a self-propagating effect, due to the fact that the compressor will have to operate under very unfavourable conditions when the circulating amount of refrigerant is reduced, so that the motor gas-cooling is also reduced. Consequently, the winding temperatures rise and, at the same time, the increased pressure conditions result in increased discharge gas temperatures.

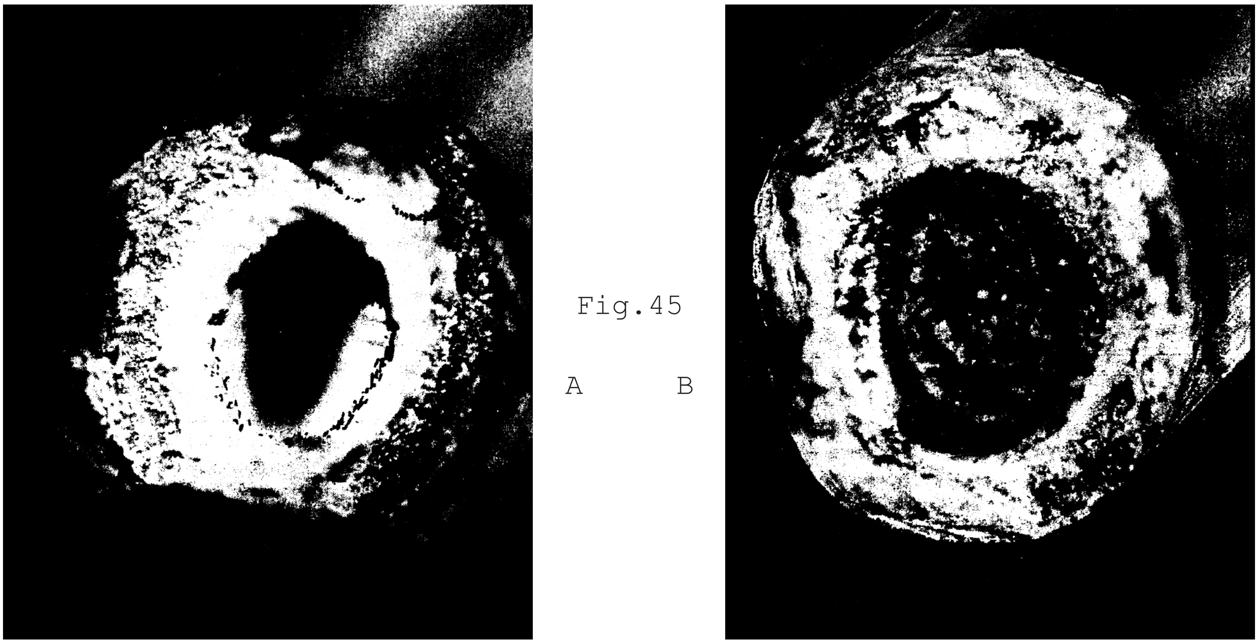


Fig.45

A B

In practice, a condition is very easily arrived at where the compressor operates with a very hot motor and very hot valves. This may result in complete clogging-up of the capillary tube as a result of the deposition of decomposition products from the oil and perhaps also from the insulating materials. In the worst case, the discharge valve becomes coked up, the motor is burned out, and the system become contaminated.
The resistance in a capillary tube can be unintentionally altered, e.g. by contact with the warm compressor. This may cause vapour to form in the capillary tube, some variety of "vapour seal" then reducing the passage of refrigerant liquid.

The effect of this "seal" will normally not be very considerable, but may be sufficient for the disturbed equilibrium of the system to give an impression of refrigerant shortage.

UNINTENDED CHANGE OF CONDITION IN CAPILLARY TUBE.

(THE CAPILLARY TUBE IS TOUCHING THE WARM COMPRESSOR)

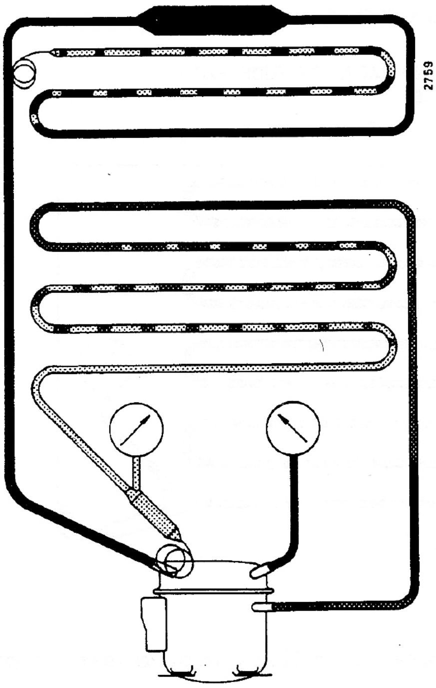
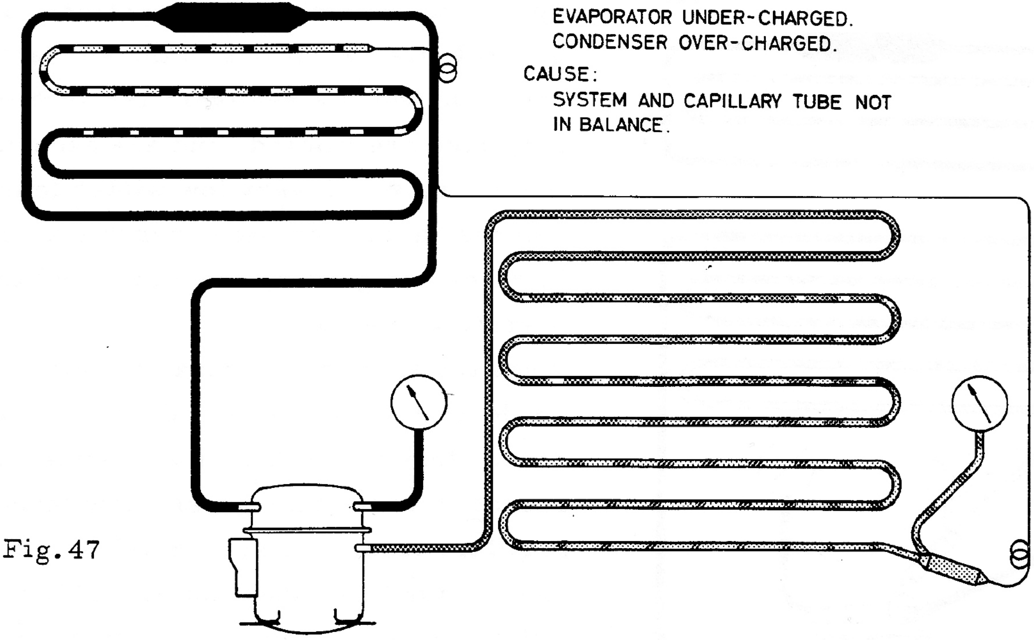


Fig.46

It has previously been mentioned that systems with capillary tubing can be best used under limited operating conditions only. This also applies to the ambient temperature. In general, the variations in the ambient temperature to which a refrigerating system is subjected are limited, and are ascertainable. In countries with very low winter temperatures, a curious phenomenon may occur, however, originating from the capillary tube operating method.
When the ambient temperature falls, the condensing pressure is reduced. In extreme cases, this may result in a considerable reduction in the refrigerant flow through the capillary tube. The system tries to compensate for this reduction by the "accumulation" of refrigerant in the condenser. The effect may to some degree resemble that resulting from partially clogged capillary tubing. On the face of it, the impression may be given that the system has lost its charge.
The worst thing to do in such a case is to refill the system. If this is done, trouble will occur when the ambient temperature increases again, due to the fact that the evaporator is then overfilled, so that the condensing pressure may become critical. The foundation may very well have been laid for a subsequent service call.
The trouble described above will generally occur in refrigerators with a fan-cooled condensing unit or a skin-type condenser. This can be artificially remedied by trying to increase the condensing pressure for a while.

This can be done by reducing the condenser efficiency, i.e. partially covering it or by switching off the fan.
There is, however, a risk of forgetting these primitive measures whenever the ambient temperature is normal again.
Under climatic conditions in which this trouble may occur, it is therefore necessary to instruct the users so that refrigerators are always installed in the correct surroundings. Alternatively, a permanent solution may be found by arranging that the fan is cut out by a thermostat, for example, when the ambient temperature drops below a certain level.
The problem in question should always be borne in mind during servicing of refrigerators working at ambient temperatures below 0°C~32°F. But the actual limit to correct operation may vary from system to system.

INFLUENCE OF VERY LOW CONDENSING PRESSURE.



EFFECT OF DEFECT:
EVAPORATOR UNDER-CHARGED.
CONDENSER OVER-CHARGED.
CAUSE:
SYSTEM AND CAPILLARY TUBE NOT IN BALANCE.

Fig.47

In refrigerating systems contaminated with moisture, capillary tube obstruction may be caused by precipitated ice.
The effect will be like that of any other form of obstruction of the capillary tube. However, there is this difference - the clogging-up effect ceases when heat is supplied to the point of obstruction. This can be done by stopping the compressor for a short period so the ice is allowed to melt. It will generally be necessary to expect repeated obstruction soon after the compressor has been restarted.

Refrigerant R12 may contain very small quantities of water. The lower the refrigerant temperature, the lower will be its water content. If the temperature falls below the limit for a given water content, the water is precipitated, and if this process takes place at temperatures below 0°C~32°F this will be in the form of ice crystals.

The precipitation of water will obviously take place in the metering device, because a marked pressure and temperature reduction occurs at this point. The ice will gradually form on the inside of the capillary tube, and after a very short time the passage may be obstructed.

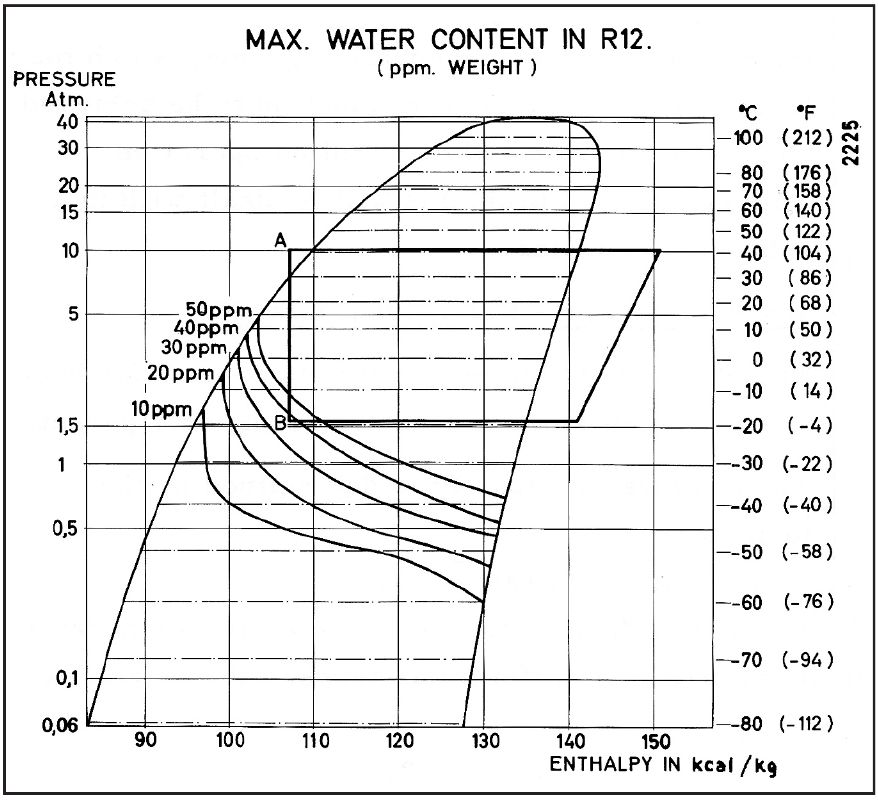


Fig.48

If obstruction caused by ice is experienced, the system must be opened. In less serious cases it will suffice if the drier and the refrigerant charge are replaced. In more serious cases it may be necessary to replace the compressor. (The procedure is described in T.-H.N.5.2.1. and MK-A/F5).

On the other hand, it is quite inadvisable to try to remove the trouble by using a so-called "antifreeze agent". By using such agents the moisture problem is obscured, but the case is not removed. Antifreeze agents are very deleterious to the slot insulation of the compressor motor, which can be completely destroyed, while at the same time corrosion and copperplating in the refrigerating system are encouraged.
Many compressor factories, Danfoss included, make therefore reservations in their guarantees-against the use of "anti freeze agents".

The narrow cross-sectional area of the capillary tube requires very special care during fitting and repairs.

Fig.49A shows the correct position of the capillary tube in the drier.

However, positioning as shown in Fig.49B may bring about various problems. During soldering, the solder material may easily clog the capillary tube inlet. During operation, small circulating particles will be guided directly towards the capillary tube, and the probability of obstruction is thus increased. This risk is reduced if the tube is fitted as shown in Fig.49A. In this case, there will be a good chance of the particles being precipitated in the cavity round the capillary tube inlet. This will be so, whether the drier is fitted in the vertical or horizontal position.

Fig. 49C shows the other extreme. In this instance, the capillary tube inlet is not unrestricted, and the resistance is increased. Complete obstruction may take place very rapidly in this case. An important factor to be considered in conjunction with capillary tubing used as a metering device, is the so-called pressure equalizing time, which may be decisive for the correct function to be achieved during thermostatically controlled operation.
This complex of problems will be dealt with in a subsequent chapter.

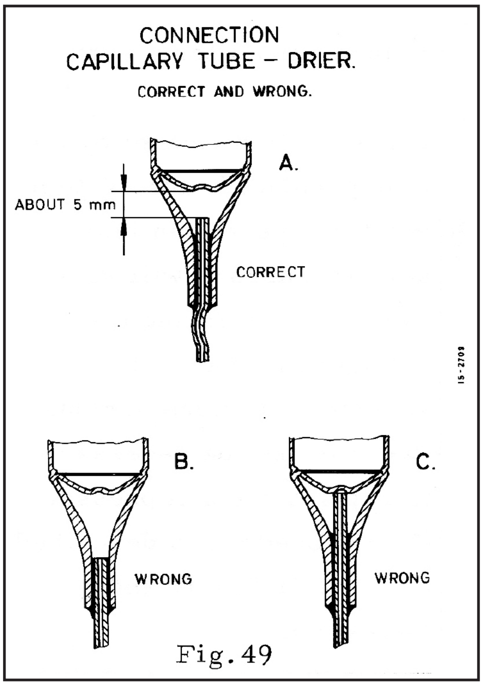


Fig.49

3. 3 Evaporator - Refrigerant Charge.

The objective of the evaporator is to transfer heat from the cold store to the circulating refrigerant.

The evaporator capacity is determined by the formula:

$$Q = K \cdot F \cdot \Delta t \ [kcal/h]$$

where K is the transfer coefficient in $kcal/h \cdot m^2 \cdot °C$, F is the active evaporator surface in m^2 and At is the mean temperature differential between the refrigerant and the ambient air.

From this formula, it is possible to determine the irregularities which may occur in and around the evaporator.

The transfer coefficient K is changed in the case of increased "insulation" of the refrigerant relative to the medium (air) around the evaporator. Simple examples are abnormal oil deposits inside the evaporator channels or external ice and frosting-up.

The formation of ice and frost may also influence the area of the active evaporator surface.

In freezers, it is normal to use evaporators of the "tube-on-sheet" type. It is extremely important for the evaporators that the tubes are in close contact with the plate material. This is ensured by using "straightened" tubes, by properly fastening them, and by careful application of the contact mass. In far too many instances, these rules are not observed, resulting in "capacity loss".

It often happens that the transfer coefficient in polyurethane foam freezers is impaired because the insulating material has penetrated between the evaporator tubes and the plate material. Faults of this nature can be avoided, by separating the tubes and the insulation by foil, tape or similar materials.
The temperature differential Δt can be determined as the difference between the refrigerant mean temperature and the mean temperature of the medium (air) surrounding the active evaporator surface.

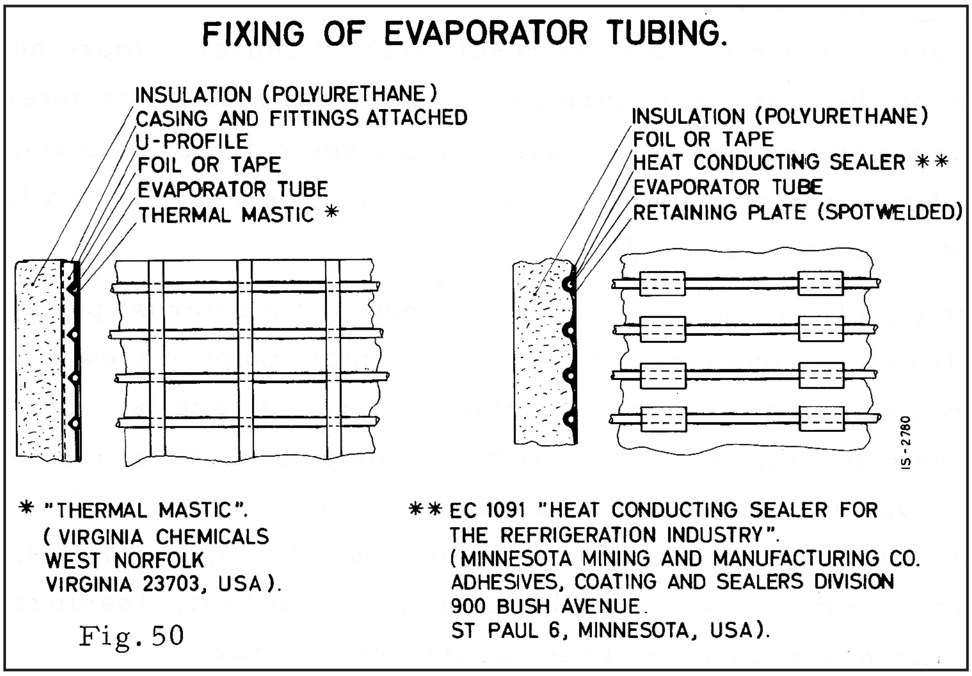


Fig.50

By depositing "warm" goods in a refrigerator or freezer, the temperatures on the evaporator surface are affected, and the ingress of heat may be said to be increased. This fact influences the evaporating pressure, which will increase depending on the amount of heat ingress and the compressor superiority. Increased heat ingress therefore results in improved evaporator utilization which is made possible by improvement of the mean temperature differential Δt and the transfer coefficient K. This is counteracted by an increase of the evaporating pressure, so that the compressor is utilized at a higher capacity.

Temperature apportionment in conventional type refrigerators is generally arranged by limiting the air circulation. Drip trays and other coverings are used for this purpose.

If it is desired to maintain a low temperature in the evaporator section, for example, an efficient cover should be fitted round it.

The evaporator is therefore utilized at a relatively poor transfer coefficient and a relatively low evaporating temperature (low compressor capacity). It is therefore necessary to accept the fact that stringent demands on temperature conditions in the evaporator section result in increased evaporator and compressor costs.

If the covering round the evaporator in a refrigerator is diminished, the temperatures in the evaporator section increase, while the temperature in the refrigerating section decrease. Using the same compressor, the heat will therefore be transferred at a higher evaporating temperature (improved compressor capacity) and at a better transfer coefficient and a better mean temperature differential on the evaporator.

In cases where the temperatures which can be obtained in a refrigerator must be estimated, it is therefore extremely important that the air circulation takes place as arranged by the designer. Above all, the original drip tray should be used and must be placed in the correct position.

The evaporator surface: Under utilization conditions which are otherwise identical, a larger active evaporator surface will always result in the removal of more heat. If economies are made on the evaporator surface, the result is that the compressor has to operate at a lower evaporating temperature for a given refrigerating requirement to be satisfied. Hence it becomes necessary to use a compressor with a larger rated capacity (a greater number of cm^3/rev).

The proper evaporator is, of course, not only determined by its external physical dimensions — neither from an economical nor from a technical point of View - but just as much by the optimum utilization of its surface. A prerequisite is, of course, that the charge of the refrigerating system is correctly adapted, and that the surface is adequately covered by tubes or channels distributed correctly. Especially in the case of freezers equipped with "tube-on-sheet" evaporators, the tube lengths are often the subject of unjustifiable economies. At best, "savings" achieved have to be compensated by expenditure on the compressor.

Fig.51 shows examples illustrating the effectiveness of a freezer in relation to the evaporator quality. The results shown in Fig.51A originate from a freezer with badly located tubes, while Fig.51B shows the same freezer with an improved evaporator.
The difference between evaporating temperatures should be noted.
In the first case, the heat transfer possibilities from the freezer goods to the evaporator were poor, resulting in impaired freezing capacity. The freezing time should be noted.

The evaporator surface will only be effectively utilized if ample quantities of refrigerant are supplied through the metering device. In refrigerating systems with a thermostatic expansion valve, the evaporator surface is uniformly utilized under all operating conditions because a definite superheat, e.g. 7°C~13°F is ensured at the bulb.
On the other hand, the flow through a capillary tube varies with the pressure and temperature conditions on either side of the tube. In general, the capillary tube is selected so that the evaporator has optimum, or nearly optimum, utilization, when the system functions in

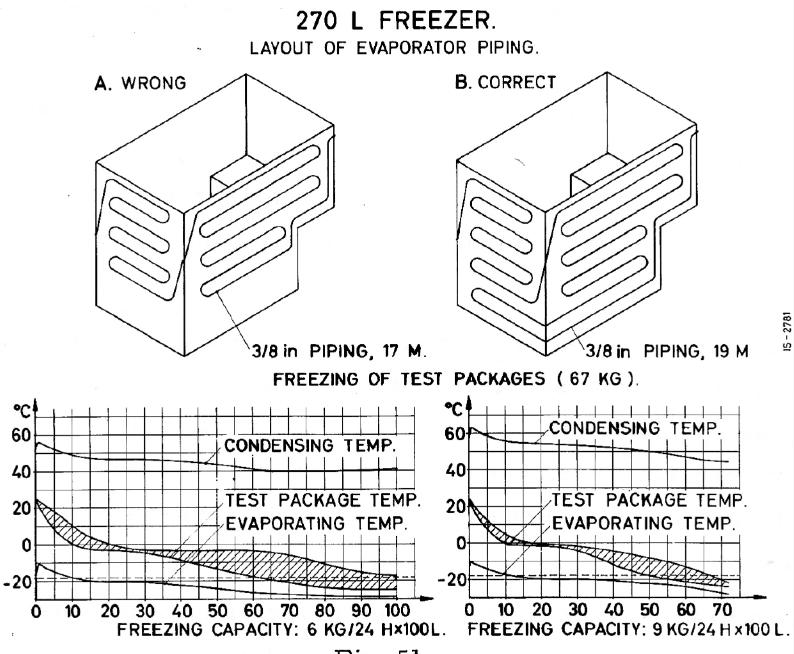


Fig. 51

the stabilized cooled—down Condition. This means that under other conditions where the load is heavy, e.g. pull-down, it is necessary to accept "insufficient" refrigerant influx.

Fig.52 illustrates this fact.

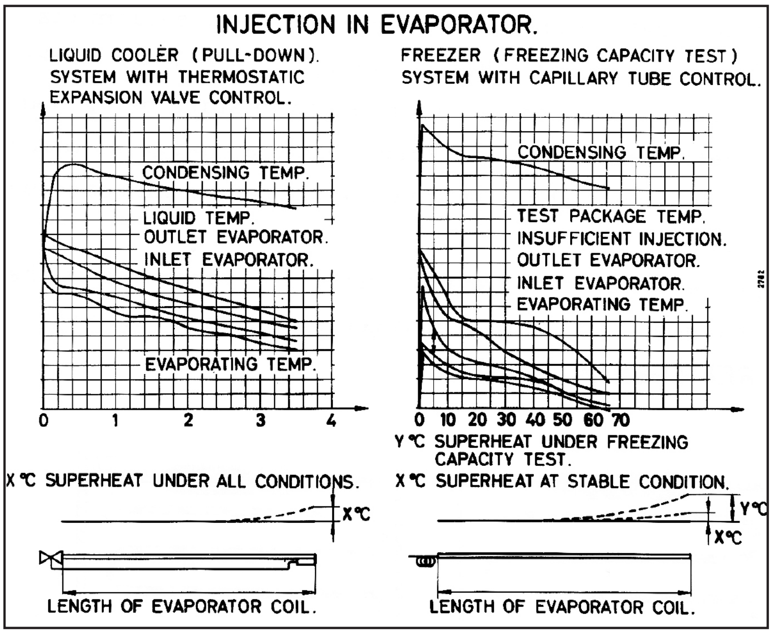


Fig.52

One diagram shows the refrigerating cycle of a liquid cooler equipped with a thermostatic expansion valve. During almost the whole refrigerating cycle, there is a nearly constant superheat across the evaporator.
In systems with capillary tubing, conditions are different, in particular because there is no receiver and, as a result, no refrigerant reserve. The maximum charge volume is limited by the criteria on which it is based, e.g. frost on the suction line, condenser utilization, etc. Operating conditions may, therefore, occur where the "correct" charge is insufficient.

Fig.52 also shows a diagram of the freezing test to which a freezer is subjected. Note how the evaporator is insufficiently utilized during the first 30 - 40 hours of the refrigerating cycle because the charge is "inadequate" as long as the ingress of heat is substantial.

This phenomenon may be more or less pronounced, depending on the design of the system, but in general it will have to be accepted.
A typical complaint about a refrigerator may be related to "insufficient cooling". If the complaint is supported by facts, the serviceman will quickly concentrate on the evaporator on the assumption that the system may have lost some of its charge. It is, however, important that any evaluation of the temperature conditions on the evaporator surface should be based on the actual operating conditions. In the case of a deep-freezer which has just been filled with goods, the basis of evaluation is, by and large, of no use. It is, of course, possible to wait until a suitable freezing period has elapsed, and then to evaluate the temperatures achieved in the freezer. If there is reason to believe that the system has lost some of its charge, it will often be necessary to remove the goods so that the surface temperatures can be measured without being affected by the cold accumulated in the goods.

The adequacy of the charge must be evaluated with the compressor operating continuously and after the temperatures in the refrigerator have stabilized.

If the "coldest" thermostat position does not result in 100°7¢ operating time, the thermostat must be short-circuited.

The evaporator will have optimum utilization if the temperature is constant from inlet to outlet, i.e. when no superheat occurs. It is, however, very seldom that such utilization is permitted because, among other reasons, it may result in the formation of frost on the suction line and, hence, the risk of moisture being transmitted to the insulation. Most refrigerator manufacturers fix the charge so that in fact the evaporator is slightly "undercharged"; a small temperature increase being allowed across the latter part of the surface.

Fig.53 is a diagrammatic representation of the conditions in an evaporator in the undercharged, the normally charged, and the overcharged states, respectively. Overcharging of a system will manifest itself, first and foremost, by frosting-up of the suction line. It should be remembered, however, that the suction line may temporarily frost up immediately after the start of a cooled-down system, even though the charge is correct.

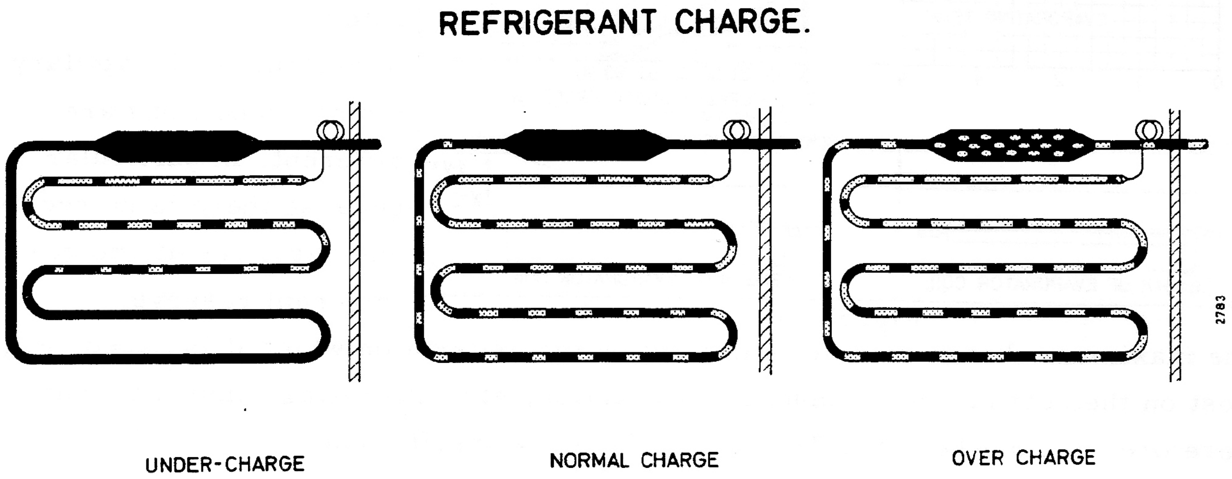


Fig.53

This is due to "priming" of the refrigerant in the evaporator at the moment of starting.

If a system is considerably overcharged, typical indications will be: large wattage consumption and increased evaporating and condensing pressures. A detailed examination may show incidentally that the condenser contains an increased liquid volume. "Overcharging" may also result in depreciation of the "lowest starting voltage" from the temperature-equalized state (see 2.42).

"Undercharging" will, as previously mentioned, result in the evaporator not being fully utilized. The result is a prolonged operating period and, possibly, that the desired temperatures are not obtained in the refrigerator.

If a bulb temperature is not reached which makes the thermostat trip, the compressor will, of course, continue to operate.

In extreme cases an abnormally low evaporating pressure may be found, and this also applies to the wattage consumption. At the same time, there may

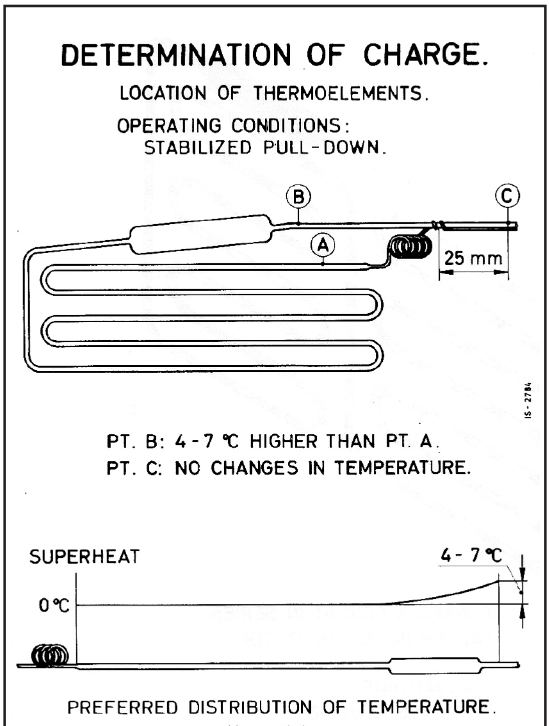


Fig.54

be a tendency for the compressor to operate at high housing and winding temperatures because of the low gas density.

Fig.54 shows the criterion upon which Danfoss bases its determination of correct charging, i.e. 4-7°C~7-13°F superheat across the evaporator.

When dealing with cases where the charge may be the cause of the trouble, it is very important also to be alert to other troubles with corresponding fault indications, i.e. primarily capillary tube restrictions (see 3.2). In addition, it must be remembered that capillary tubing and charge can only be adjusted to optimum operation at a specific ambient temperature. As described in 3.2, this can mean that, for example, low ambient temperatures may cause an accumulation of refrigerant in the condenser because of too low a condensing pressure. The result is insufficient refrigerant supply to the evaporator.
In cases where a refrigerator has lost some of its charge, it is necessary to assume that the trouble originates from a leak. It is therefore important not only to remedy the trouble temporarily by "recharging", but also to locate the leak and to repair it, so that repeated service calls are avoided.

Oil return: Small quantities of oil circulate in any refrigerating system. They are harmless as long as the oil is not retained in the system.
Under adverse circumstances, the oil can be deposited in the evaporator, resulting in incomplete return. If the worst comes to the worst, this can mean a dangerous reduction of the oil quantity which is available for the lubrication and cooling of the compressor. The diagram in Fig.55 shows how a small reduction of the quantity of oil has an insignificant effect on the operating conditions of the compressor. If, however, the quantity of oil is substantially reduced, the heat transfer to the compressor housing is reduced, and the winding temperature increases. At some time, the quantity of oil may have become so small that no further lubrication takes place. The current consumption will, therefore, increase, and the moving parts of the compressor will soon seize up.
Correct oil return need not be a problem. In general, it is simply a question of keeping the gas velocities above a definite minimum limit. In nearly all domestic refrigerating systems, R12 gas velocities of between 3 and 5 m/second are used in the evaporators.*)

*)Pohlmann in: "Taschenbuch für Kältetechniker" specifies R12 gas velocities of 4 - 9 m/second on the suction side of small refrigerating plants.

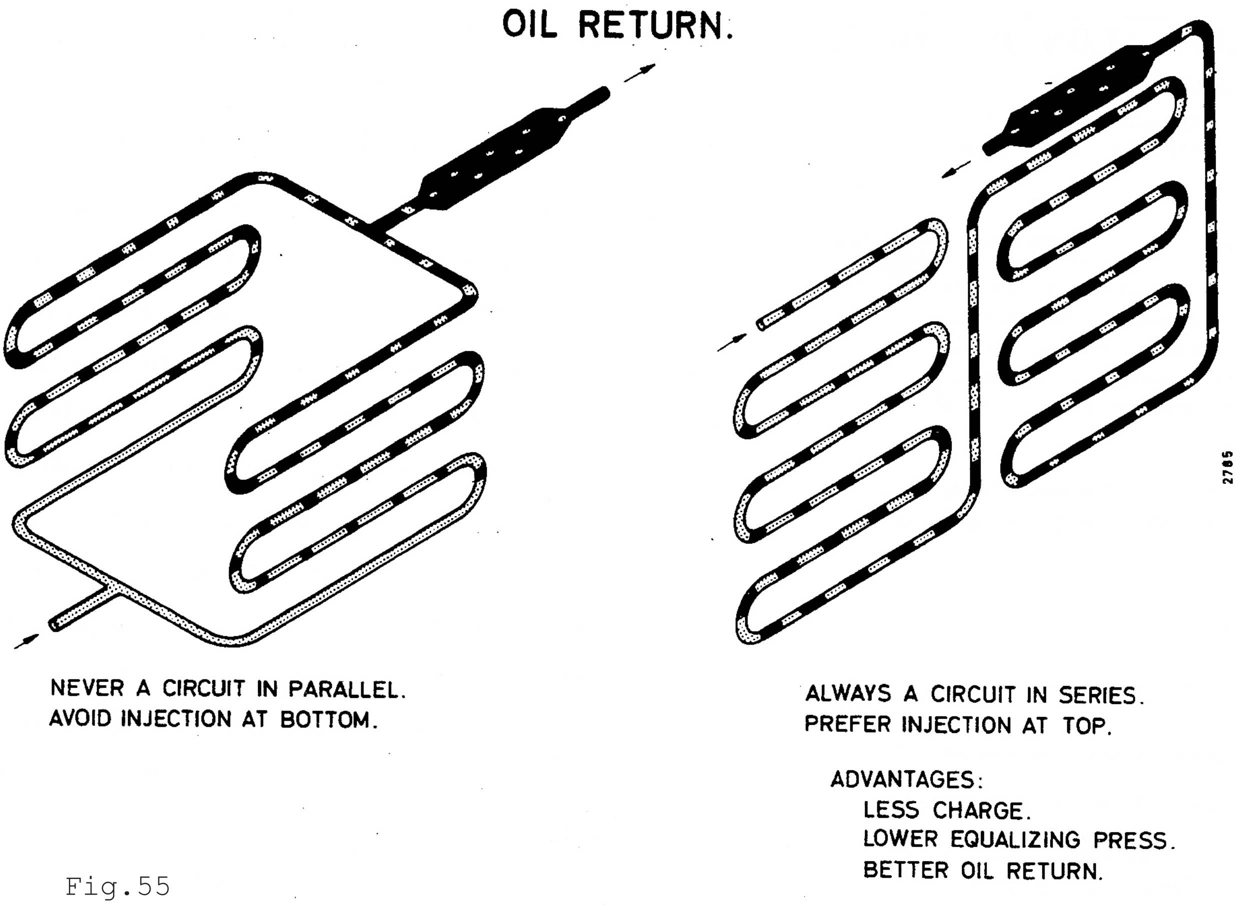


Fig.55

In this way, effective oil return is ensured without any substantial pressure loss across the evaporator. Incidentally, if troubles are experienced in a "tube-on-plate" evaporator, it is always possible to alter the tube dimension "on the way".

While a well-dimensioned series circuit will never cause trouble as regards oil transport, conditions are more problematic in parallel circuits, such as are often used in small "roll-bonded" refrigerator evaporators. However, the possibilities of oil accumulation are also remote in these systems. On the other hand, a parallel circuit, as shown in Fig.55, must be considered as very dubious. The risk of the gas velocities being different in the two parallel halves is real, and hence the risk of oil accumulation is also real. It is consequently advisable to treat parallel circuits with caution.
In principle the evaporator circuit may be designed for injection either "at top" or "at bottom".
Considering oil return, there is probably an advantage in using evaporators with injection "at top".
For relevant pressures and temperatures, R12 is completely miscible with recommended refrigerating machine oils. However, this is not the case with all refrigerants. Hence, conditions are quite different for e.g.R22, R115, and the azeotrope R502, (R502 consists of 48.8% R22 and 51.2% R115).

For example, at low evaporating temperatures, very little oil can be dissolved in R22. If the quantity of oil is increased, separation of oil and refrigerant occurs. It has, therefore, often been the practice to mix R22 with 5 - 10% of R12 so as to ensure oil return.

R22 is gradually being displaced by R502 for LBP purposes, but the oil return problems are the same. Experience shows, however, that by exerting adequate care during the dimensioning and running of tubes, it is possible to avoid troubles. In the case of R502, Du Pont has set up the following rules of thumb:

a) The velocity in vertical tubes must not be less than 3.7 m/sec.~
750 ft./min. In vertical riser pipes, velocities of 7.4m/sec.~
1500 ft./min. or more are recommended.

b) Evaporator tubes and return lines should be laid out with a slight downward gradient, but an oil trap should be fitted ahead of vertical riser pipes.

Fig.56 shows the miscibility of R502 and an approved type of compressor oil.

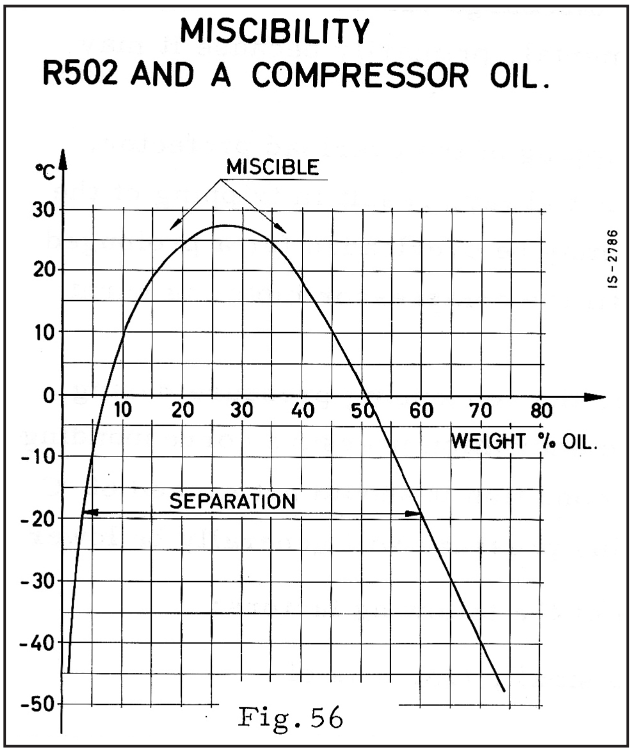


Fig.56

Various defects: Evaporators, especially in refrigerators, may suffer from other faults and defects. They are often subjected to mechanical injury by knives or sharp tools being used to loosen ice cube trays and frozen goods. This procedure may result in damage to the surface finish or, in the worst cases, in actual punctures. Especially with "roll—bonded" aluminimum evaporators, very serious galvanic corrosion may occur when the surface finish is damaged. If the unprotected aluminium surface comes into contact with copper ions, corrosion starts at once. Copper ions may be contained in melt water from overlying copper tubes, and in countries where domestic copper vessels are used, corrosion may occur if such a vessel is temporarily placed on a damaged evaporator surface. More common are the instances of galvanic corrosion occuring at the copperaluminimum connecting pipe joints, originating from poor protection of the joint against moisture and food acids. Even if minor corrosion damage can be repaired (see MK-A/F5, section 8), it is generally necessary to face the fact that most evaporators which have been subjected to galvanic corrosion must be scrapped.

3 . 4 The Condenser.

The compression heat from the compressor is removed in the condenser, together with the heat transferred to the refrigerant in the evaporator. During normal operation, superheated vapour occurs at the condenser inlet, while slightly sub-cooled liquid occurs at the condenser outlet. The latter phenomenon varies, however, with the temperature conditions under which the refrigerating system is used. At low ambient temperatures, there will thus be a tendency for the lower tubes of the condenser to be filled with liquid to a higher degree.
The condenser may give rise to two different kinds of operational fault:

During operation, the heat emission effect may be insufficient, i.e. the condensing pressure becomes too high.

During standstill periods, the condenser design may be such that liquid remains in pockets, evaporating slowly and thus increasing the so-called equalizing period.

When the condensing pressure increases, the compressor capacity decreases. At the same time, the work of compression is increased, i.e. the current and power consumption of the compressor increase, and the discharge gas temperature also increases. This may result in coking-up of the discharge valve.
Abnormally high condensing pressure is detrimental, primarily because it may cause overloading of the compressor.
The overloading may be such as to result in tripping of the overload protector. The fact that a high condensing pressure does not always result in tripping of the protector may be dangerous. The compressor may be overloaded for a prolonged period, but the overloading is not observed until the compressor motor is burnt out.
In a statically cooled R12 refrigerating system, the condensing pressure during pull-down and freezing of ice should not exceed saturation pressure corresponding to 68-70°C~154-158°F while in the stationary condition it should not exceed 60°C~140°F. In a fan-cooled system, the condensing pressure will generally be lower.

A high condensing pressure may be due to one of the following factors:

a) The condenser may have been selected too small, i.e. it is of faulty construction.

b) The condenser cooling conditions may be bad, either on account of incorrect building-in or the inexpedient positioning of the refrigerator.

c) The condenser may have been badly maintained, e. g. dust which has accumulated in the course of time has not been removed. This may be especially the case with finned condensers. (Fig.57).

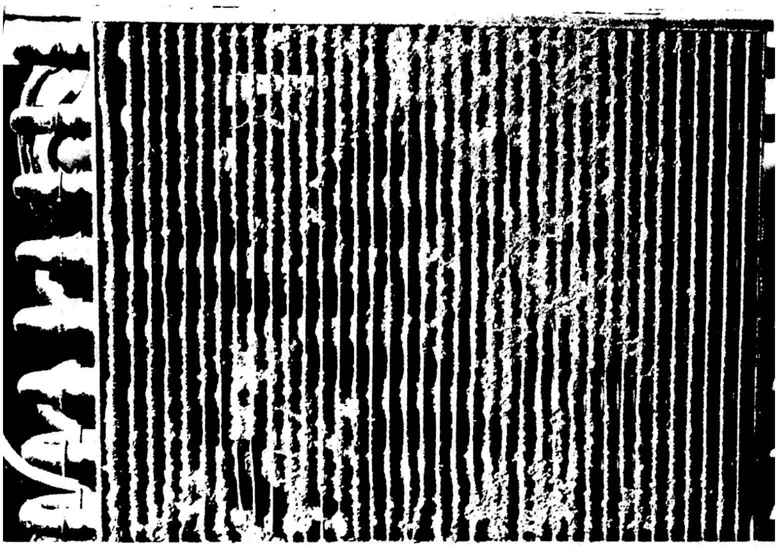


Fig.57

d) In addition, the fan of a fan-cooled system may be defective.

The condenser design must not influence the equalizing period of the refrigerating system. The design should therefore be such as to allow natural accumulation of the condensed refrigerant at the base in front of the capillary tube.
If the condenser has not been designed in this way, there will be a risk of the equalizing period of the system becoming too long, with resultant tripping of the motor-protector when the thermostat cuts in (as described in 2.3). Various factors which influence the equalizing period will be dealt with in a subsequent section.

3.5 Mechanical Compressor Troubles.

Proper operation of the refrigerator depends on the compressor being in good order, i.e. the compressor must circulate refrigerant, and in ample quantities. In the preceding sections, we have dealt with many types of trouble which result in the compressor failing to start and operate. But even if the compressor motor appears to work satisfactorily, other faults may occur to reduce or completely to impede refrigerant circulation.

Troubles of this nature can be referred to the mechanical part of the compressor, and are due either to faulty valve operation or leaks between the high- and low-pressure sides of the compressor.

Such faults may be more or less serious. They may vary in their effects from "reduced capacity" to "absolutely no capacity".
If the compressor does not circulate any refrigerant at all in the system, the result is, of course, that no pressure variations can be recorded. The evaporator will, therefore, be "warm" and the condenser will be "cold". Since no compression work is **done**, the power consumption will also be reduced.

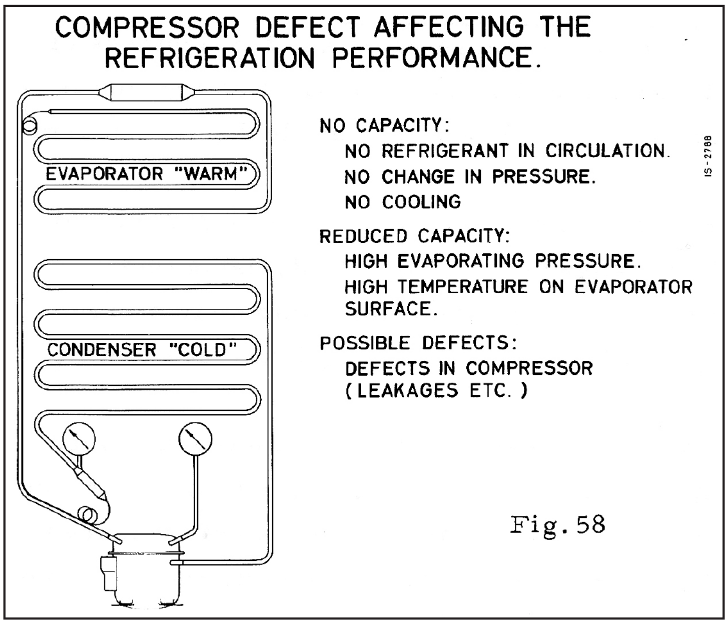


Fig.58

In the case of a small defect, the compressor will still circulate refrigerant, and the effect on the conditions in the system will be the same as if the compressor had been selected too small.
The practical result of this will be an increase in evaporating pressure and, hence, in the surface temperatures on the evaporator. At the same time, there will be a tendency for reduced condensing pressure. On the other hand, the effect on the power consumption will be less and depend on the nature and order of the defect. The best way to determine incorrect compressor capacities is by measuring the pressure in the system.
Nevertheless, mistakes can be made, especially by inexperienced servicemen. When a compressor is scrapped, it should always be further tested after removal from the system, and in any case before being returned for repair. This can be done as shown in Fig.59, since for specified conditions (compressor temperature, suction side pressure, and top pressure) the pumping capacity is measured by means of a flowmeter.

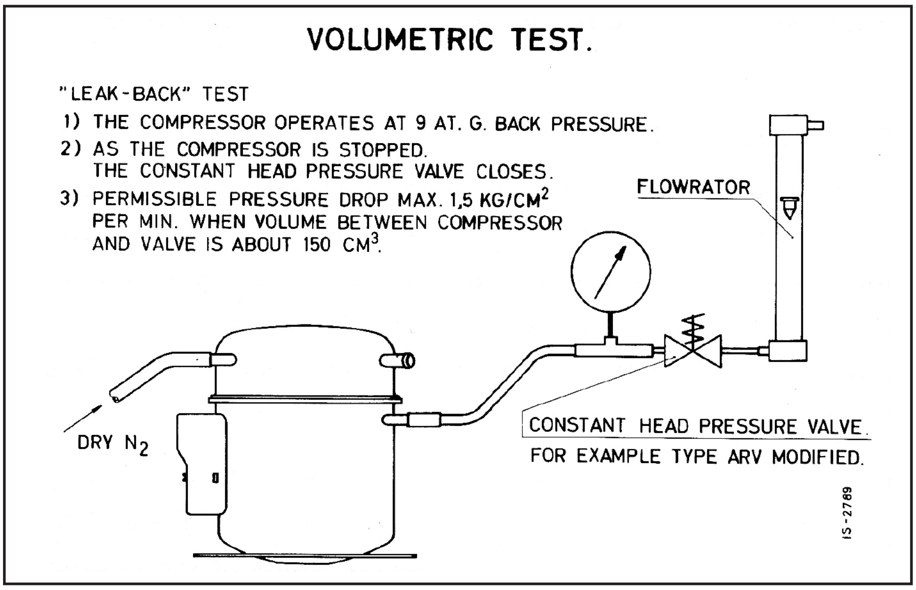


Fig.59

The test can be supplemented by testing the discharge valve and the tightness of the delivery side, the compressor being stopped at the same time as the line is shut off at the flowmeter. Any pressure drop will then indicate leaks in the compressor.
Danfoss has developed a preliminary test equipment (see T.-H.N.5.2.2. Fig.5), which to some extent can replace the arrangement in Fig.59. By using this equipment it is possible to test whether the compressor can pump up to a predetermined top pressure e.g. 9 atm.g.~128 psig. In addition, leak-back testing can be carried out.
This is done by stopping the compressor, since the built-in back-pressure valve then closes at a small pressure drop. The test equipment gives a rough impression only of the compressor pumping capacity, since the air volume is not measured. Experience shows, however, that if the compressor stands the test, there is comparatively little likelihood of a capacitative defect.

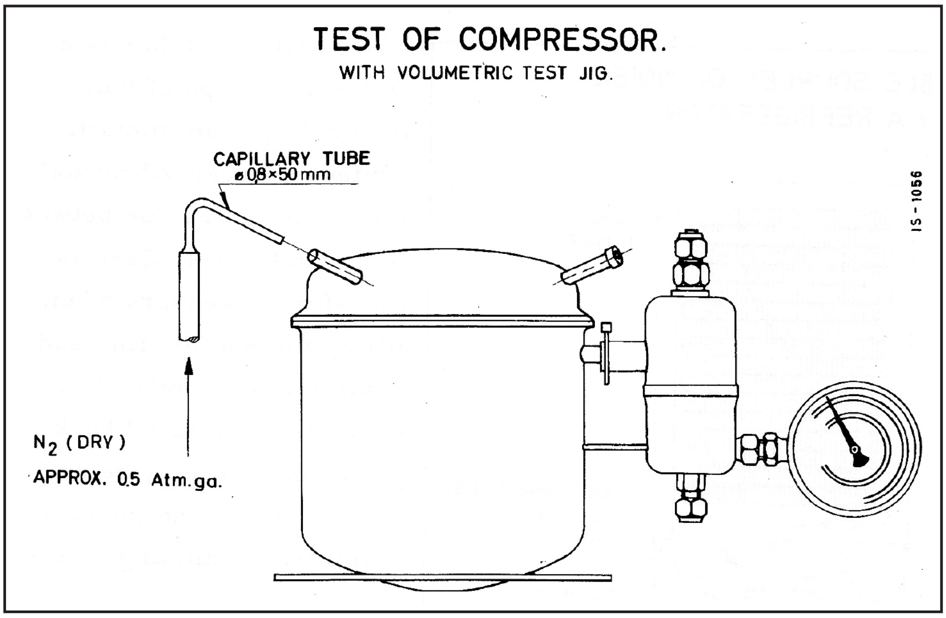


Fig.60

Complaints are occasionally received concerning refrigerator noise level, and the compressor is generally considered to be the source of the noise. Such complaints may be correct, but quite often they are not. By and large, it is possible to distinguish between two categories of compressor noise, i.e. noise caused by actual mechanical defects and a more subjectively determined noise.

As regards mechanical defects, the cause of complaint can be irritating metallic noise during operation which can be referred to the interior of the compressor. Such troubles, which may originate, for example, from damage in transit, are generally so self-evident that they need not be discussed further here.

It is a different matter with more subjective complaints, because the noise level which is satisfactory to the average consumer may not be satisfactory to more critical ears. In the same way, it is obvious that a refrigerator may be unacceptable in one room, but acceptable if moved to another.

When a complaint is considered justifiable, it will certainly not always be the compressor which is the source of the noise.

The noise level is largely dependent on the way in which the compressor is built into and fixed to the refrigerator.

Fig. 61 shows different fitting and construction faults which may be the case of the noise complaints.

The noise emitted by a compressor can be divided into the categories of "air-borne" noise, vibrations, and gas pulsations.

The latter two "types of noise" may cause the construction elements to vibrate when certain external conditions prevail.

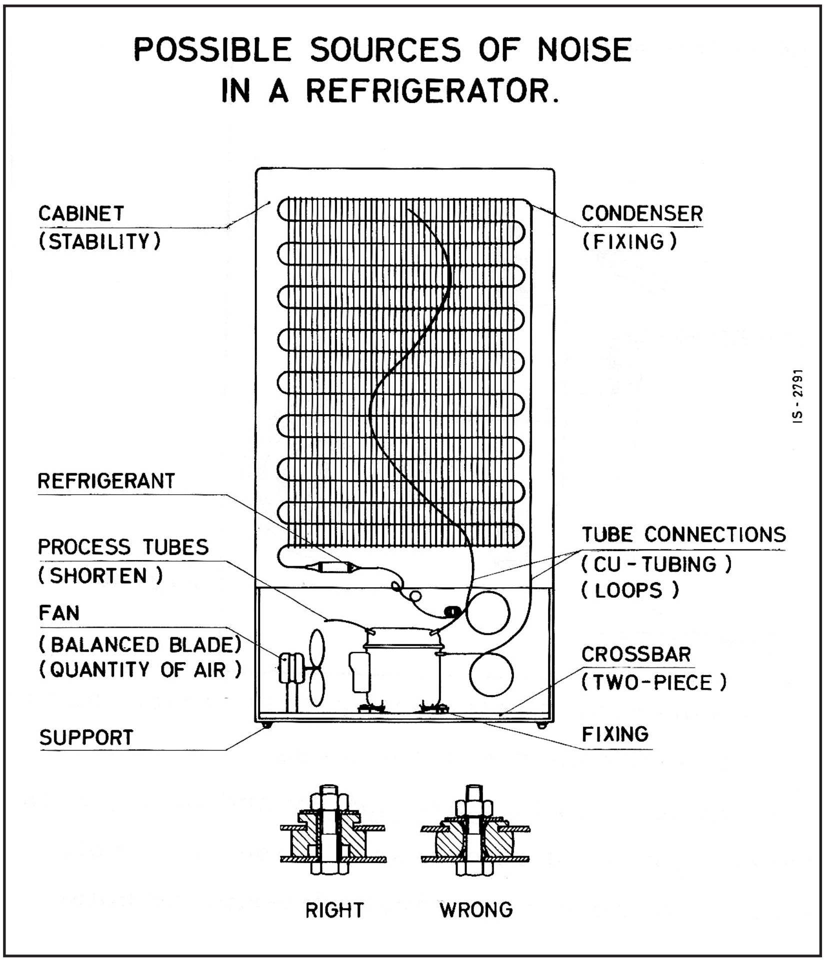


Fig.61

The rattling of tubes is a wide spread type of noise originating from metallic contact between vibrating tubes and plates, or between individual tubes. Care is therefore necessary when fitting the suction line and capillary tube coils. For example, behind a "back condenser" it may be necessary to fix the tubes in a vibration-damping material.

Many vibrations can be damped-out by equipping the delivery line and, if necessary, the suction line also with a tube winding. Sometimes, up to 25cm~10in. of process tube is left on the compressor. This length of tube may vibrate and may make contact with other tubes and plates.

The condenser may also be fixed with greater or less rigidity. The best way of fixing it is, of course, by using a method which does not result in direct metallic contact with the cabinet.

The compressor is generally fixed by means of special rubber bases. The purpose of such bases is to isolate the compressor from the crossbar of the refrigerator. The rubber bases must, therefore, not be compressed to any considerable degree as otherwise the distance piece will transmit vibrations.
The crossbars - or any baseplate in the machine room - may be badly constructed the thinner the material, the more the probability of complaints. The same remark applies to the cabinet construction proper.

It will pay to be cognizant of the possible multiple causes of noise complaints.

3. 6 Pressure Equalizing and Standstill Periods.

In refrigerating systems where capillary tubing is used, pressure equalizing takes place between the discharge and suction sides during the compressor standstill period.

Provided that this period is always long enough for pressure equalizing to take place before the compressor starts again, heavy demands are not made on the motor starting torque.

For this reason, LST compressors are normally used in systems with capillary tubing, i.e. compressors with a low starting torque.

In far too many cases, however, the prerequisites for using LST compressors are not fulfilled, since the standstill period is shorter than the pressure equalizing period. There is then a- great risk of compressor failure during restarting, manifested by the motor being unable to overcome the starting resistance. The "locked rotor" condition previously mentioned will then occur, causing the motor protector to cut in very rapidly.

Faults of this nature have to some extent been described in section 2.3. In what follows, these conditions will be further described, but with special weight attached to the influence of system components and thermostats on the pressure equalizing and standstill periods. Fig.62 shows the pressure and temperature variations possible in a system during thermostatically controlled operating and standstill periods.

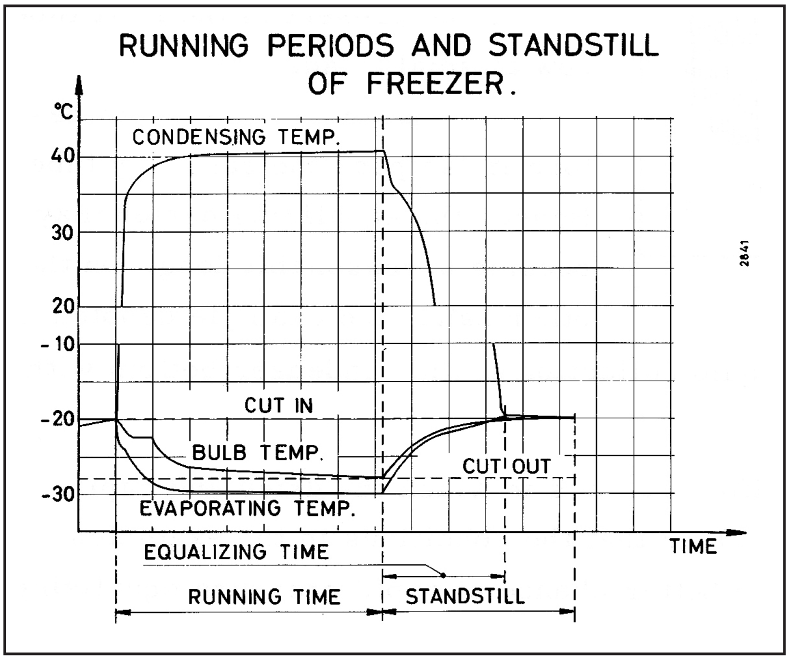


Fig.62

It should be noted that pressure equalizing is completed before the thermostat bulb attains the cut-in temperature of the thermostat.

In this instance, therefore, the standstill period is longer than the pressure equalizing period. Hence, the starting properties of the LST compressor must be considered.

It is obvious that a conflict may easily occur between the pressure equalizing period and the standstill period. The foundation of such faults may already have been established at the design stage. In other instances, conditions in the system or around the thermostat may change during the refrigerator life and give rise to complaints

- perhaps after several years of operation. In what follows, conditions affecting the pressure equalizing period are first dealt with, and then conditions affecting the standstill period are considered.

Pressure Equalizing Period.

Since pressure equalizing takes place through the capillary tube, the flow resistance in this tube is of decisive importance to the equalizing rate. The resistance may increase in the course of time, e.g. because of incipient clogging-up.

For this reason, among others, it is expedient to follow the dimensioning rule mentioned previously, which states that a capillary tube of large inside diameter and greater length is to be preferred to a capillary tube of small inside diameter and lesser length. It is also important that the refrigerant from the condenser should have direct access to the capillary tube inlet.

Refrigerant liquid is generally present in the lowest part of the condenser. Since, as is well known, liquid has a much smaller specific volume than vapour, direct liquid supply to the capillary tube during pressure equalizing will be advantageous, rather than a preceding variation of state. Allowance for this can be made by the method of condenser construction and the correct positioning of the capillary tube.

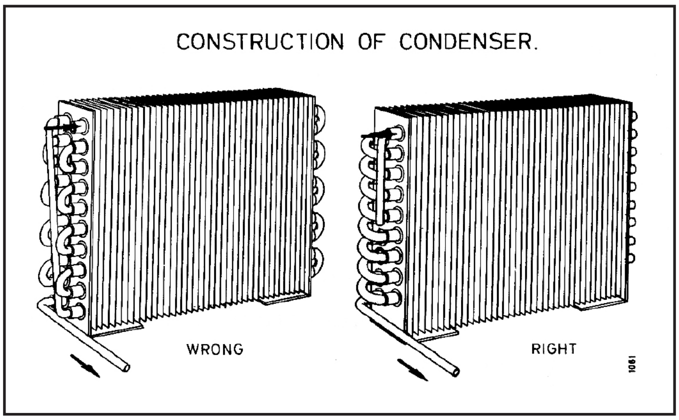


Fig.63

Fig.63 shows a two-row condenser designed for fan cooling. If tubing is used as shown in the example marked "Wrong", liquid may already be present in the first tube row at small loads. This means that the liquid must evaporate before it can pass the capillary tube.

Hence, the equalizing period may become unreasonably long. On the other hand, the example denoted " Right" shows the effect of natural liquid collection at the condenser bottom with easy discharge to the capillary tube.

The example in Fig.64 shows three different ways in which the drier and capillary tube inlet may be arranged. It is clear that the conditions in the examples "B" and "A" to the right offer a much better chance of rapid pressure equalizing than the example to the left.

The extent of the pressure equalizing period also depends on the total refrigerant volume in the condenser.

The tube dimension used in the condenser should therefore not be larger than necessary.

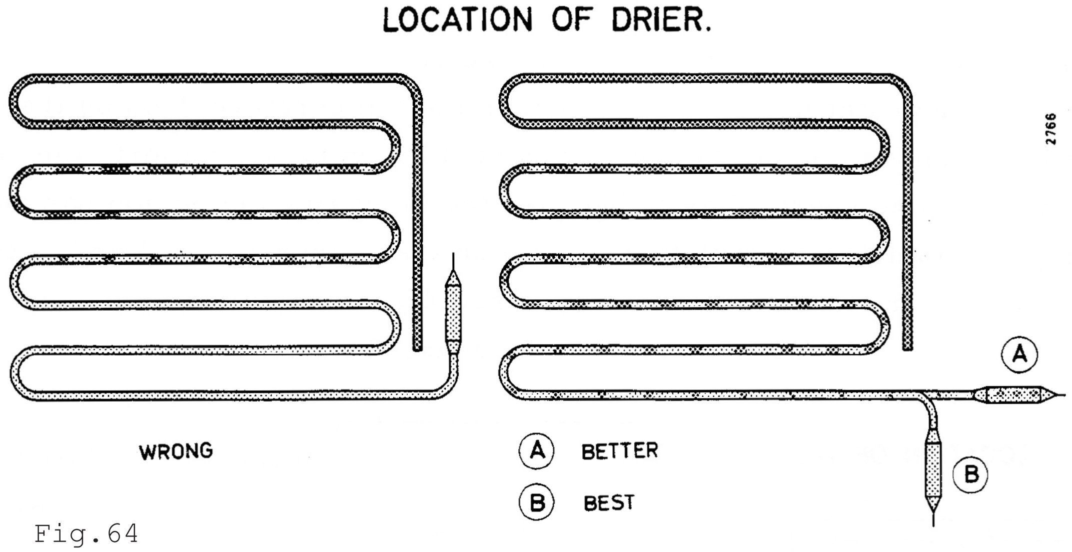


Fig.64

In simple refrigerating systems, for example conventional refrigerators, it is possible to have equalizing periods of 3 - 5 minutes. In freezers it is generally necessary to reckon on about 8 minutes.

Standstill Period.

The standstill period of a refrigerator is partly determined by the thermostat differential and partly by the rate at which the bulb temperature increases. By choosing thermostat differentials of not less than 8°C~14,4°F for refrigerators and of not less than 6°C~10,8°F for freezers, the standstill period is assumed to make suitable allowance for the equalizing period. But it is, of course, necessary for the thermostat bulb not to be subjected to rapid temperature increases.
The way the bulb is placed on the evaporator is, consequently, of some importance. The examples below are taken from a freezer with a "tube on sheet" evaporator.

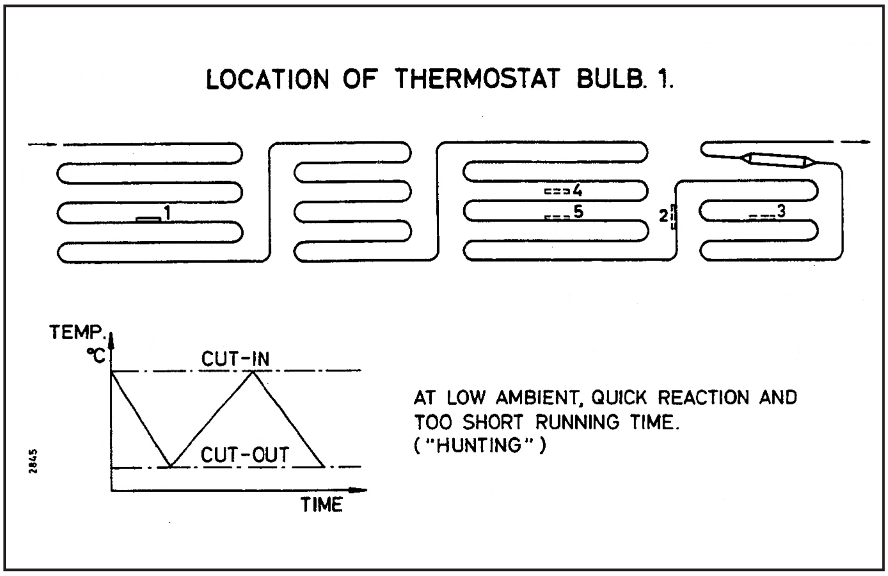


Fig.65

In principle, the bulb can be placed in one of the five positions shown in Fig.65. We shall consider the advantages and disadvantages of these different positions
If the bulb is fitted at "1", the result is rapid temperature variations at the bulb

- especially at low ambient temperatures. There is then a risk of the cut-out temperature of the thermostat being reached before the temperature drop on the evaporator has been sensed. Since the running period becomes very short, the standstill period will also be short. This is because the brief running period has not permitted any substantial accumulation of cold on the evaporator coil and in the box Hence, the temperature at the bulb increases rapidly.
A position as shown at "1" will, therefore, increase the risk of excessive running and too many protector trips.

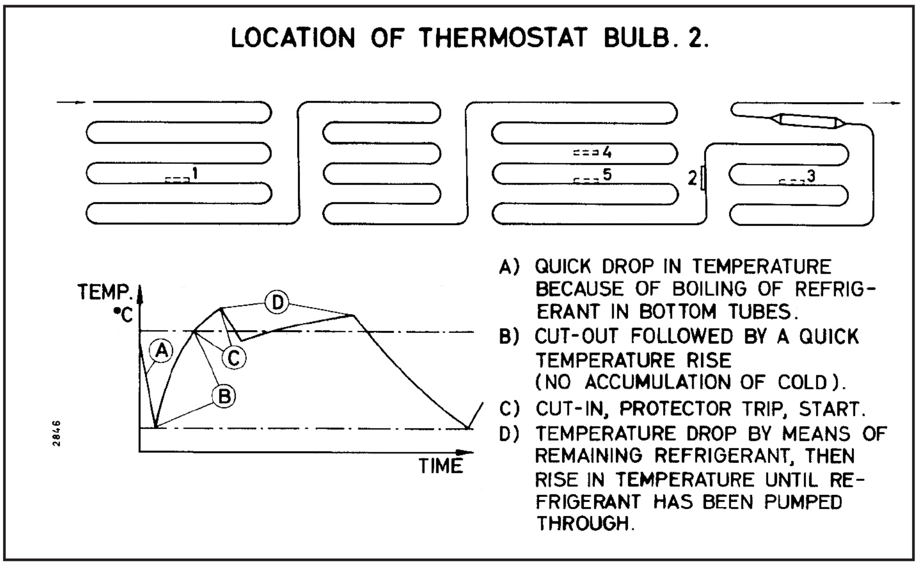


Fig.66

If the bulb is fitted at "2", there are the following risks:
A) Since refrigerant liquid always collects in the bottom of the evaporator during a standstill period, priming will take place during restarting.
This may affect the bulb, resulting in a rapid temperature drop, so that the cut-out temperature of the thermostat will soon be reached.

B) Since no accumulation of cold has taken place during the brief operating period, the bulb temperature will rapidly increase.

C) During the short period elapsing before the thermostat cuts in again, pressure equalizing cannot be achieved. The compressor will, therefore, probably fail during the subsequent starting attempt, and the protector will come into action.
Soon after the motor protector cuts in again, and if pressure equalizing has been completed, the compressor restarts.

D) The refrigerant remaining in the bottom of the evaporator will now boil away, resulting in a small temperature drop at the bulb. This drop may, however, be succeeded by a transient temperature increase, because it may be some time yet before the refrigerant from the evaporator inlet reaches the bulb. Not until then will there be a correct temperature drop and, hence, an actual running and standstill period.

Position "3" is also unfortunate, because the bulb is actuated much too easily by variations of charge in the system.

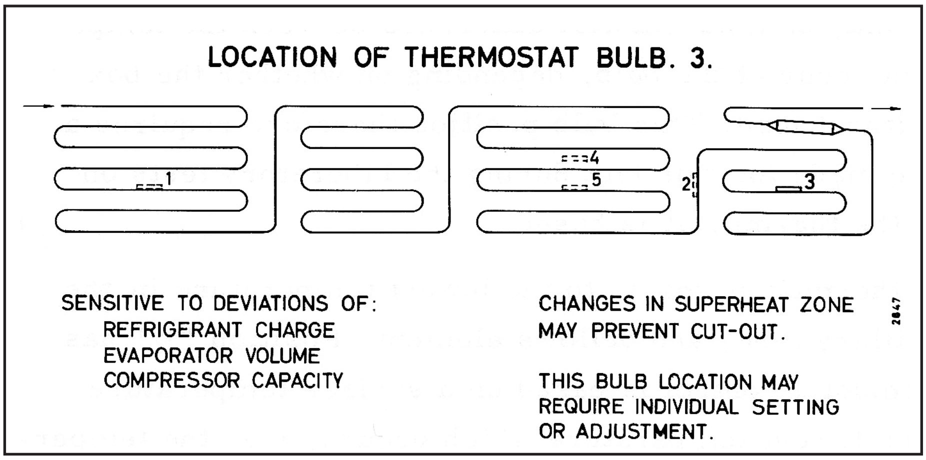


Fig.67

It is possible for mass production manufacture to result in an unfortunate combination of absolute charge, total evaporator volume, and compressor capacity, causing the system to be insufficiently filled.

During operation with the consumer, it is also possible for the system to lose some of its charge. Such a deviation from the optimum charge volume may not prevent the freezer being used as planned, but since it increases the superheating zone at the evaporator end, it can prevent a sufficient temperature drop at the bulb, so that the thermostat does not cut out.

Position "3" may, as is evident, result in increased running time or even 100% running time. On the other hand, there will be no trouble with pressure equalizing and protector tripping.

To remedy the fault, it is necessary to readjust the charge in the system or to adjust the thermostats individually.

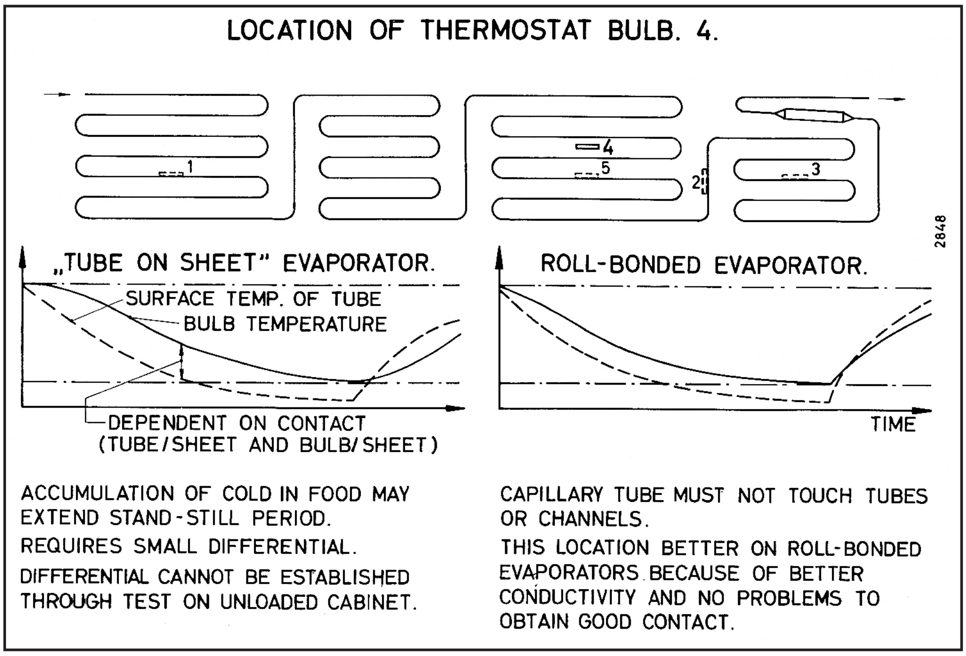


Fig.68

If the bulb is fitted as shown in example 4, the following conditions must be noted:

A) As the bulb is fitted directly on the inner box, it can be affected by the actual load conditions.
If, for example, a number of parcels of frozen goods are placed near the bulb, the cold accumulated in these parcels may extend the standstill period.

B) As compared with examples where the bulb is placed on evaporator coils or channels, position "4" requires a smaller thermostat differential.

C) According to A, there may be a substantial difference between the temperature sequences which occur at the bulb, depending on whether the box is operating with or without load. This bulb position therefore requires a special allowance to be made for this fact during the laboratory tests on which the selection of the thermostat is based.

D) As is well known, the thermostat reacts to the lowest temperature in the assembly of bulb, capillary tube, and bellows element. Position "4" has the effect that the thermostat control is based on a surface temperature which is higher than the lowest temperature which occurs, i.e. the temperature at the evaporator coils. This bulb position is, therefore, especially sensitive to instances where the thermostat capillary tube may make contact with the evaporator coils or channels. In such cases, the running and standstill periods are shortened, and there is a risk of protector tripping during restarting.

E) Position "4" will also be affected by any failure of contact between the evaporator coil and the inner box.
In the case of poor contact, the temperature difference between the bulb and evaporator coil is increased.
Position "4" is, therefore, more suitable for roll-bonded evaporators, because these are more likely to give good heat conduction.

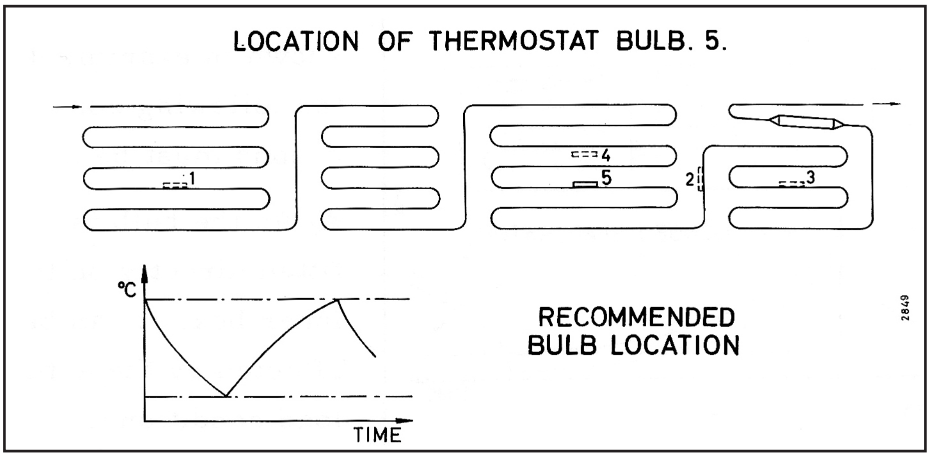


Fig.69

Position "5" does not result in the disadvantages described for the other bulb positions. It is therefore recommended that this position should be used, especially in the case of freezer evaporators of the "tube on sheet" design.

In order that the thermostat should act as intended, not only is correct positioning of the thermostat bulb necessary, but the bulb pocket must also be of proper design, and good contact must be ensured between the bulb and bulb pocket, as well as between the bulb pocket and evaporator.
Fig. 70 shows some of the mistakes which can be made.
Here, the bulb pocket is of incorrect design, since there may be some doubt as to the actual bulb position.

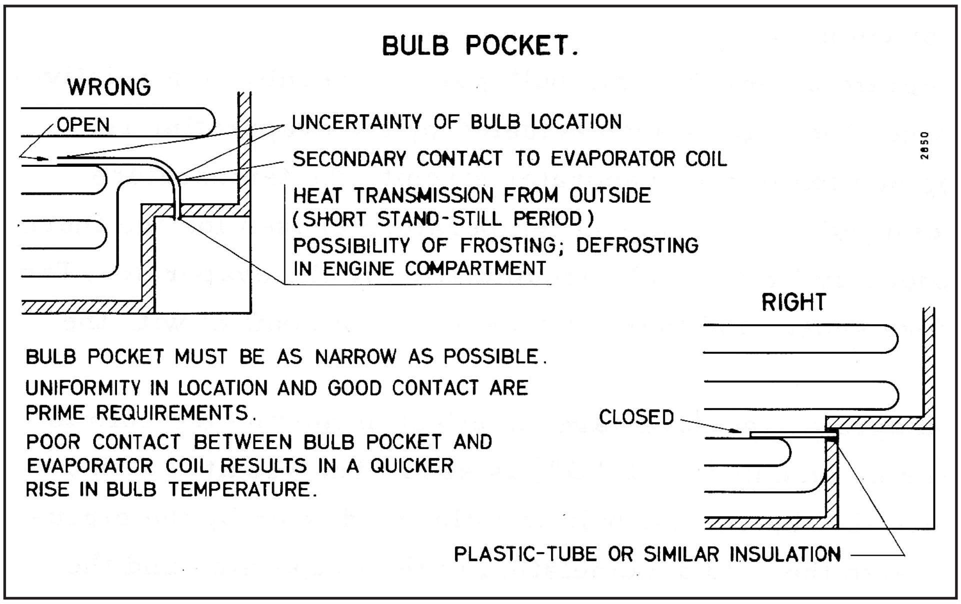


Fig.70

If the bulb pocket had not been bent and if it had been closed at the end, the bulb could have been placed as required with greater ease and security.

The bulb pocket shown is also wrong because it crosses the evaporator coil, thus increasing the risk of secondary contact with the evaporator. Another fault is that the bulb pocket - due to its projection into the machine room - permits heat transmission between the machine room and the evaporator. Hence, the bulb may be adversely actuated so that the standstill period is shortened, and the risk of protector tripping during restarting is increased. Another disadvantage is that the bulb pocket shown may cause ice to form on the projecting portion, with subsequent transmission of melt water to the machine room during standstill periods. An old rule-of-thumb is that the thermostat bulb should preferably be fitted in the last third of the evaporator circuit. Fig.71 shows that this rule also applies to refrigerator evaporators, and that the conditions described above in regard to the positioning of thermostat bulbs on freezers also apply to some extent to refrigerator evaporators.

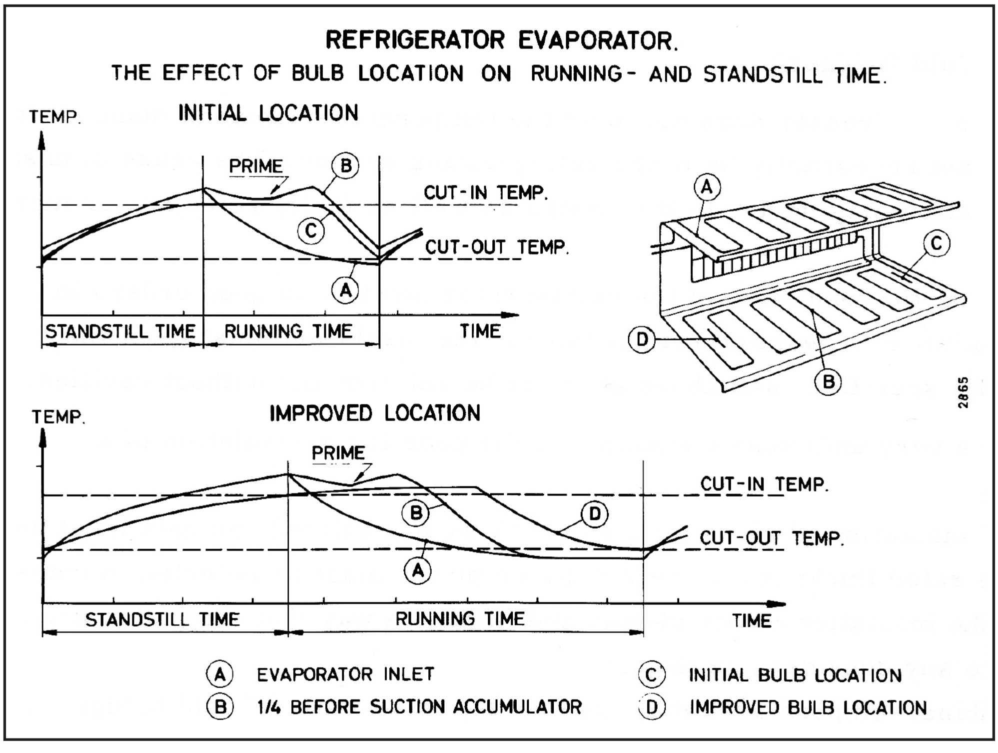


Fig.71

The inlet of the evaporator shown is at point A. B is a measuring point situated a quarter of the distance along of the series circuit from the end.

The bulb was originally fitted at point "C".

The upper temperature diagram shows that this bulb position results in a relatively short running period, since the bulb is soon actuated by the evaporating refrigerant. On the following section of the evaporator circuit, the temperature reduction is reduced and delayed. At the cut—out temperature chosen for the thermostat, the result is a considerably limited cold accuinulation in the evaporator. The standstill period is therefore short, and there is thus a risk of conflict with the equalizing period.

In the lower temperature diagram, the advantageous effect of moving the bulb to a point further on in the series circuit (point "D") is seen. The result is a prolonged running period, since the thermostat bulb is influenced later by the circulating refrigerant. Hence, also the cold accumulation in the evaporator and the standstill period are increased. Because of the alteration shown, the percentage running time has been increased from approx. 52% to about 59% only.

The bulb position chosen (D) is the best solution in the present case.

However, wherever practically possible, it is preferable to avoid placing the bulb on the bottom horizontal face of the evaporator, since in this position it may be affected by frozen goods and ice trays.

Incidentally, there is a risk of the cold accumulation in such cases increasing the standstill period to an unreasonably high degree. The result may be incipient defrosting at the evaporator top which is undesirable.

4. Refrigerator Insulation.

Insulation - "Cold Bridges".

If a refrigerator or freezer does not meet the temperature demands made on it, the fault need not necessarily be in the refrigerating system. The cause of unsatisfactory operation may be due to bad design as well as faulty refrigerator manufacture.

It is obvious that the insulation of the refrigerator must be in good order. Inparticular, with foam-insulated refrigerators, the insulation must be of the specific gravity specified, and above all must be uniform and without cavities.

Fig.72 shows a very unfortunate example of the poor foam-insulation of a freezer. Similary, the insulation of glass wool and rock wool insulated cabinets must not collapse. The rated thickness of the insulation plates must be selected in compliance with the insulation cavity chosen and in such a way that the plates are not compressed to any considerable degree.

Inadequate cabinet temperatures may also be due to so-called "cold bridges", i.e. sections of the construction where heat transmission from the outer to the inner cabinet may occur because of conduction or convection. Such faults will be most frequent around frame and door seal sections.

Fig.73, section A, shows a very poor assembly of inner and outer cabinets. In. this case, a polyurethane-insulated refrigerator was involved, and the inner cabinet was made of enamelled steel plate. The moulding used provides quite inadequate insulation, and it was actually found that the K·F-value of the cabinet could be reduced to 80% of the original value by reducing the heat conduction.

Fig.73, section B, shows a more modern frame design for a polyurethane-insulated cabinet.

Fig.72

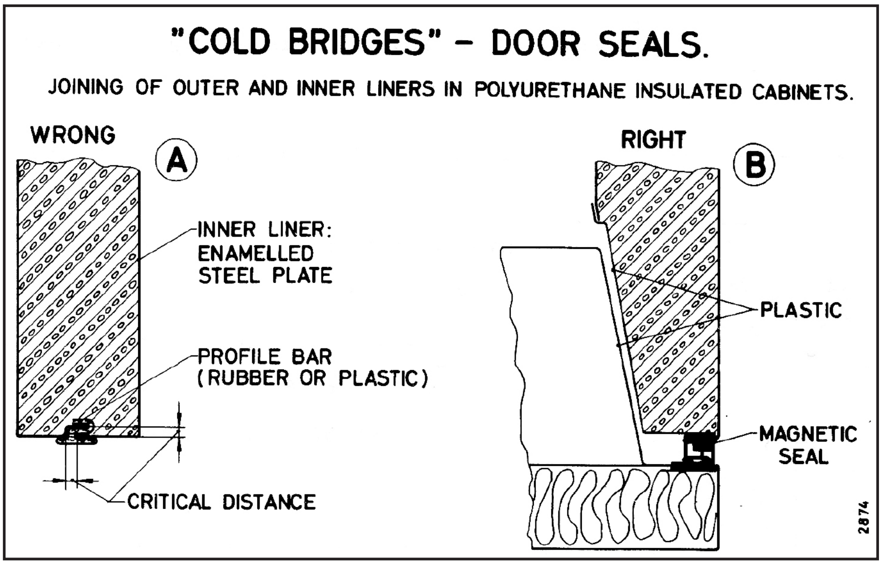


Fig.73

Fig. 74 shows two closely related designs of frame pieces and door seals in glass wool insulated cabinets.

In the example, section A, the length of the inward-bent fin of the outher cabinet can be criticized, since it may have an unfavourable effect in freezers. The example in Fig.74, section B. is ideal.

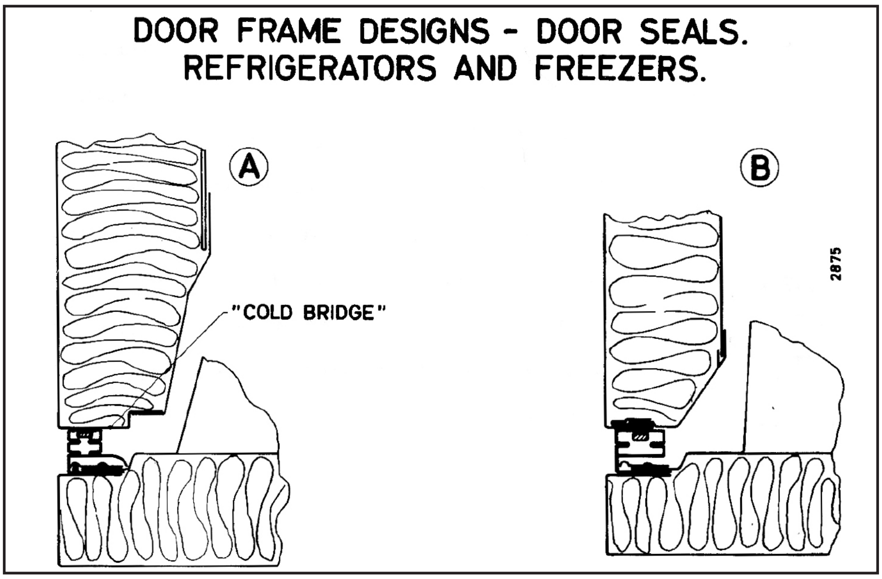


Fig.74

Fig. 75 shows another type of cold bridge. In the example shown, the inner cabinet has been centered relative to the outer cabinet by means of a few welded-on distance pieces. In this way, direct contact is created between the inner and outer cabinets. The freezer in question was equipped with an anti-dew coil, presumably because the "cold bridge" made it necessary.

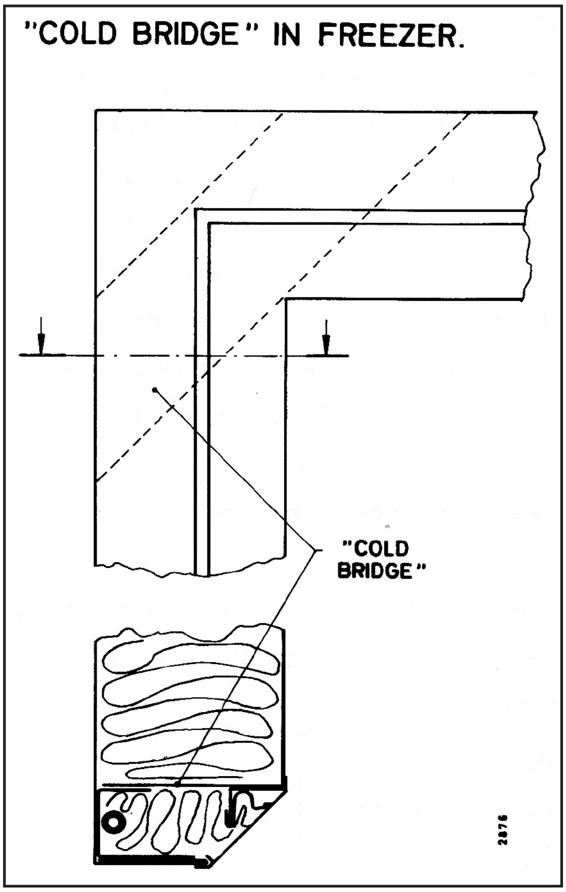


Fig.75

With the anti-dew coil out of operation, it was ascertained that the surface temperature around the cold bridges was 5-7°C~ 9-13°F lower than the ambient temperature.

Removing the cold bridge resulted in a reduction of the cabinet temperature by 2-3°C~ 3.6 - 5.4°F

"Cold bridges" must be avoided not only because of the capacity loss they cause, but also because they may bring about condensation on the outer cabinet. This may result in unnecessary expenditure on installing anti-dew coils or electric heaters.

Fig.76 shows the surface temperature which result in condensation of dew at different ambient temperatures and relative humidities.

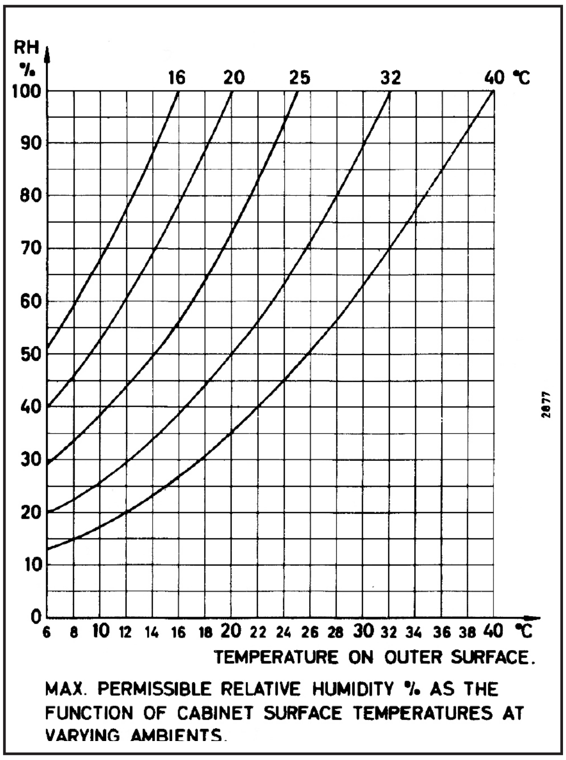


Fig.76

In combined refrigerator-freezers with two doors it is sometimes a problem to avoid condensation of dew between the doors.

Fig. 77 shows two versions of the same appliance. The original design (section A) required an anti-dew arrangement, but this could be avoided by introducing a modification, seen in section B. The modified construction of the insulation not only results in increased insulation thickness but also reduces the convection between the interior of the freezer section and the metallic centre frame.

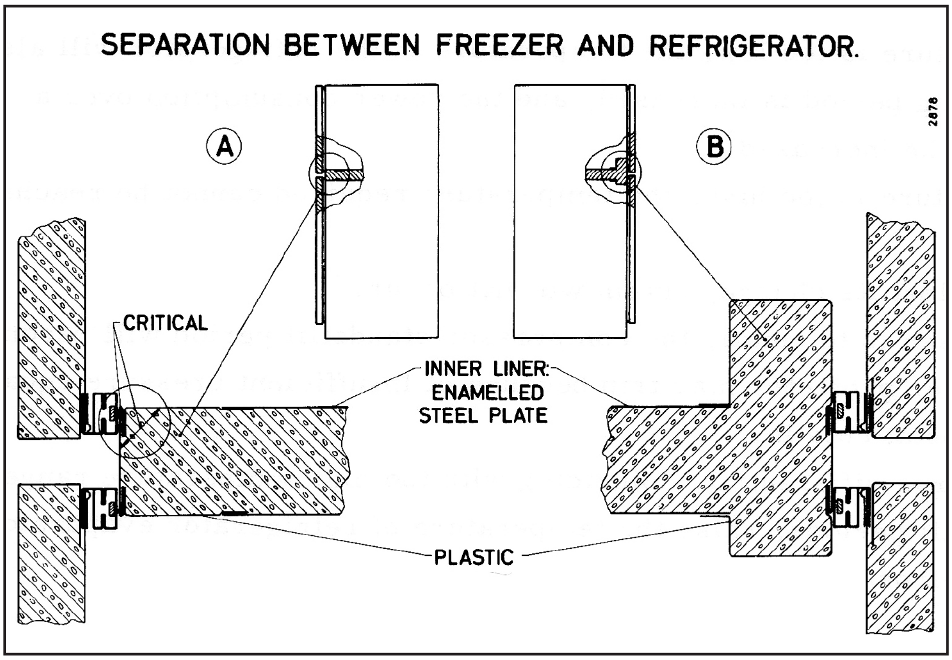


Fig.77

In some cabinet designs it may be inexpedient to increase the insulation so that condensation of dew is avoided. In such cases it is necessary to use anti-dew arrangements and disregard the resultant capacity losses.

Fig.78 shows two examples of frame arrangements in two-door refrigerator/freezer cabinets.

In one case, condensation is avoided by the use of an electric heater in the other case, heating is provided by utilizing the pressure side gas of the refrigerating system.

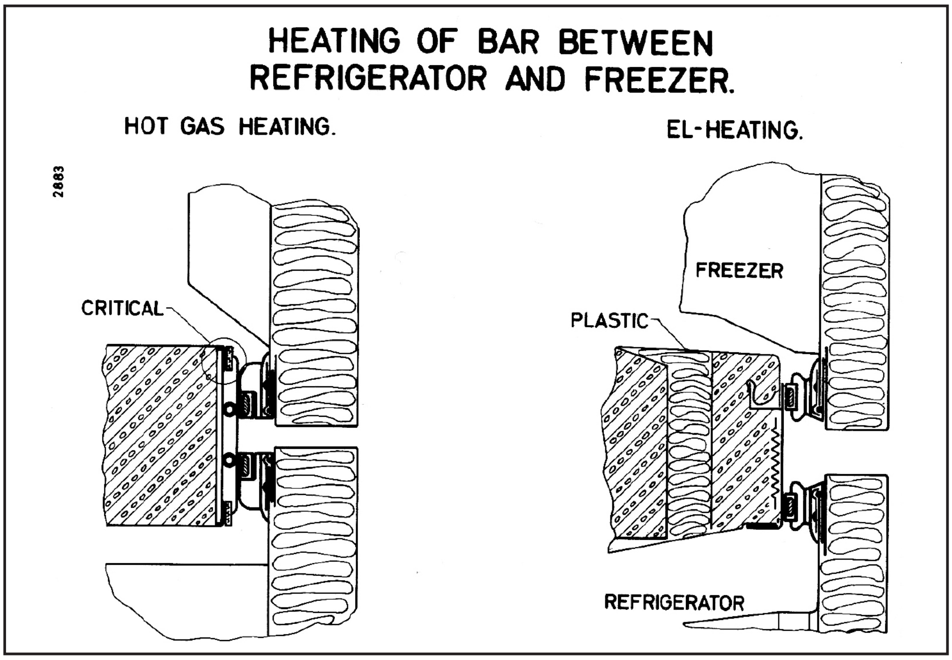


Fig.78

5. Thermostat.

The object of the thermostat is to control the temperatures in the refrigerator, and this component must be the first to be considered when abnormal temperature conditions prevail.

The thermostat may have an "abnormal" effect on refrigerator operation, for the following reasons:

The range and/or the differential may be wrong.

If the cut-out temperature is too low, the temperature in the refrigerator will also be too low. The running period is increased, and the power consumption over a given period will also be increased.
If the cut-out temperature is too high, the temperature required cannot be reached in the refrigerator.
If the thermostat has lost its charge, cut-in will not occur.
If the differential chosen is to small, the compressor standstill period will become too brief, and the motor protector may trip because of insufficient pressure equalizing when the thermostat cuts in.
The choice of a too large differential, coinciding with too high temperature range may, during stand-still periods, raise the temperature of refrigerator evaporators,enough for these to defrost.

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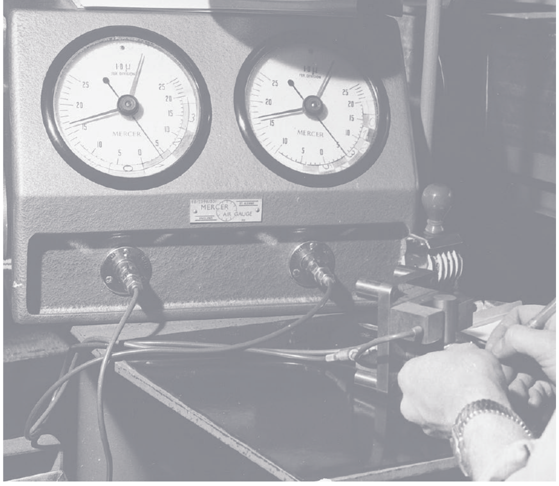
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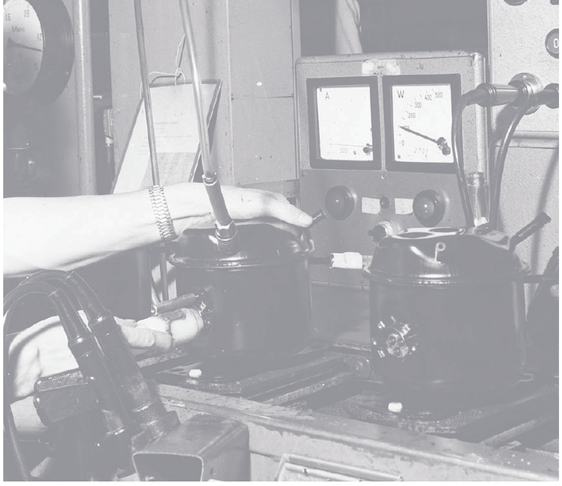
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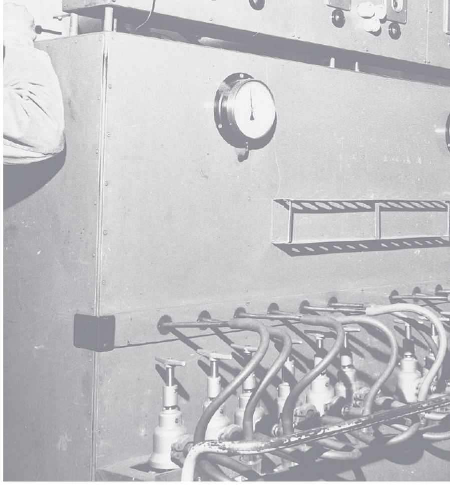
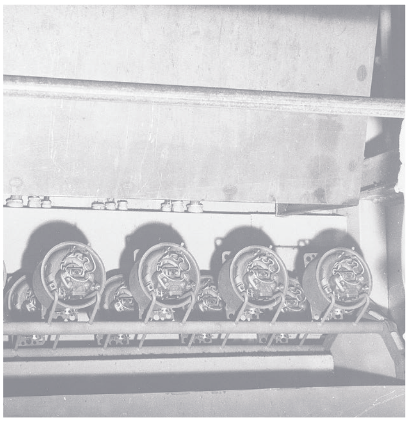
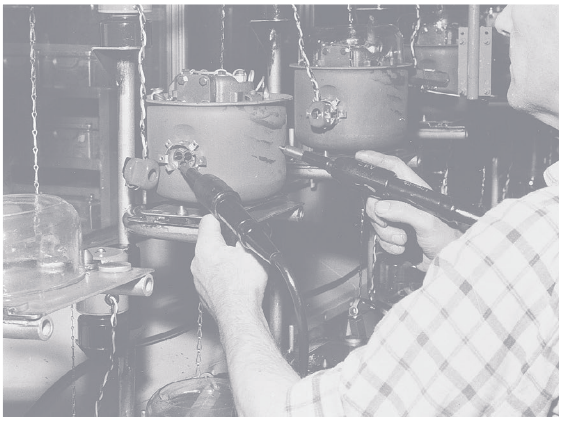
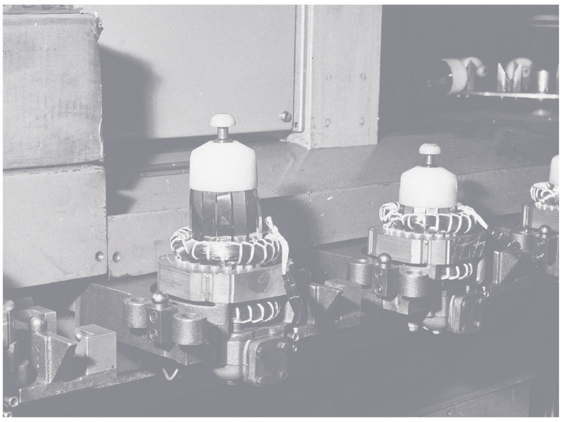
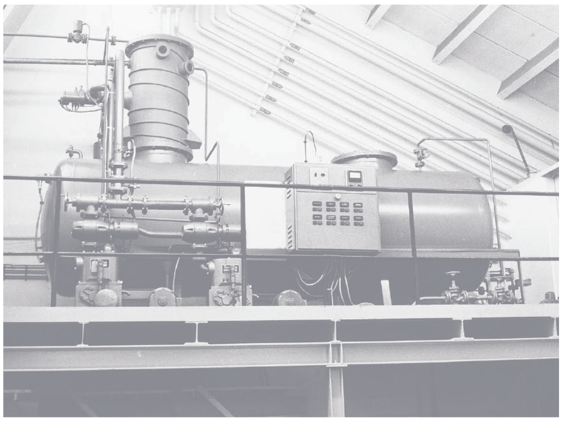
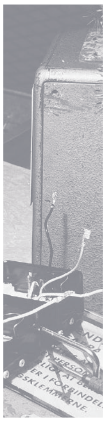


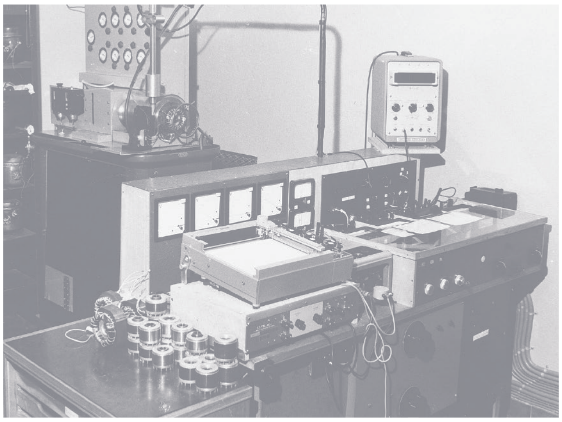


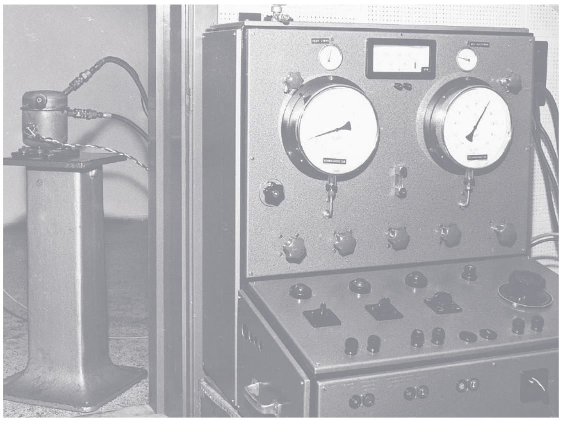


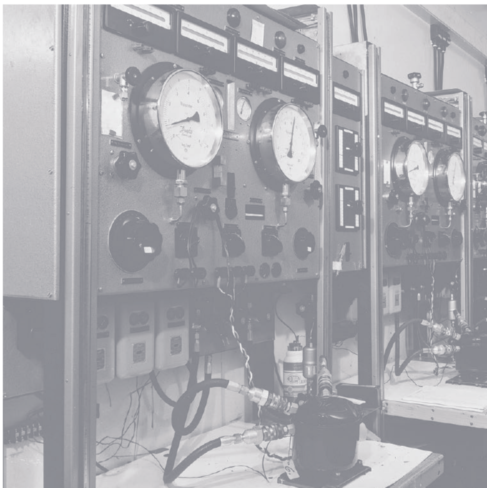








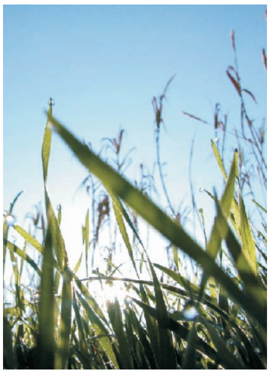




OUR IDENTITY

At Secop we are committed to our industry and are genuinely passionate about the difference we are able to make for our customers. We understand their business and objectives and the challenges of today's world of refrigeration and cooling systems.

We work in a straightforward way, being open, direct and honest because we want to make things clear and easy. Our people are committed to increasing value for our customers and constantly strive for better performance, knowing that our own progression and success is dependent on theirs.



OUR JOURNEY SO FAR

1956
Production facility and headquarters in Flensburg, Germany founded.

1958
Start of production for PW compressors.

1970
Introduction of SC compressors. The birth of a standard-setting platform in the light commercial market.

1972
Introduction of FR compressors.

1977
Introduction TL and BD compressors.

1990
Introduction of NL compressors.

1992
Introduction of PL compressors.

1993
Start of production with natural refrigerant R600a (Isobutane).
Production facility in Crnomelj, Slovenia founded.

1999
Start of production with natural refrigerant R290 (Propane).

2002
Production facility in Zlate Moravce, Slovakia founded.

2005
Introduction of GS compressors.

2008
Production facility in Wuqing, China founded.

2010
Introduction SLV-CNK.2 and SLV-CLK.2 variable speed compressors.
Introduction BD1.4F Micro DC compressor.
Introduction of DLX and NLU compressors.

2013
Introduction of the XV compressor – opening a new chapter in refrigeration history.
Secop acquires ACC Fürstenfeld, Austria.

2015
New generation of energy-efficient propane compressors.
New variable speed platforms for household and light commercial applications.

Produced by Secop | April 2016