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EXPANSION OF THE APPLICATION RANGE
OF SINGLE STAGE R 502 REFRIGERATION COMPRESSORS

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1. INTRODUCTION

The application of single stage, suction gas cooled semihermetical motor compressors is limited in the range of low evaporation temperatures by a maximal temperature (generally 150 °C) in the gap of the discharge valve. For compressors of this type a great super-heating of the suction gas occurs before the compression takes place. This is due to the resumption of the motor's loss of electrical energy, along with a rise in the compression temperature caused by the motor. Suction gas cooling is in particular necessary for higher evaporation temperatures, and therefore larger power absorption of the motor, in order to exclude an undue increase in the winding temperature (generally above 100°C) and damage which might occur. There have been experiments to investigate whether the application range of motor compressors towards lower evaporation temperatures (below -40°C) can be extended by excluding the influence of heat dissipation on the suction gas or by methods that lower heat dissipation. For this purpose a refrigeration unit with suction gas cooling was so modified, that it was possible on one hand to feed the suction gas directly into the suction chamber, on the other, to operate with switching over from delta into star circuit for low temperatures.

2. TEST ARRANGEMENT

2.1. Refrigeration Cycle

The measurements were executed in the refrigeration cycle, which is shown in figure 1, by application of the refrigerant R 502. A suction gas cooled DWM -Copeland 3-cylinder motor compressor, type D 9 RS 1- 1000L was used as the test machine. The suction gas can be fed into the compressors either through the suction shutoff valve and then through the electromotor (original condition) or through bypassing the motor through a direct inlet into the suction chamber. In a special evaporator condensor unit the generated refrigerating capacity can be utilized for the dissipation of the condensation heat. As the generated refrigerating capacity is, however, not sufficient to condense and to undercool the refrigerant, it is then led through a thermostatically controllable, water cooled heat exchanger. This permits an exact control of the variable condensation temperatures which are required for the executing of the test. The evaporation temperatures are regulated automatically by an expansion valve. After leaving the evaporator- condensator- unit the evaporated refrigerant flows through a further heat exchanger in which a thermostatically controllable superheating temperature is set, in order to fix a defined suction gas condition of $T_1 = 0^\circ$ C. This heat exchanger is fed with a brine solution, which is extracted as a cooling agent from a system permanently installed in the test laboratory.

2.2. Electrical Layout

The electric motor of the compressor was fed by three phase current with a nominal voltage of 380 V. A star-delta -switch permitted a star-delta-start of the electro-motor, which on the one hand lowered the initial current peak and on the other hand made it possible to run the motor with a lower voltage (i.e. in star-circuit) to try to diminish the winding current. The compressor D 9 RS 1- 1000L is equipped by the manufacturer with thermistors that protect the windings from overheating. These open the control circuit when the maximal admissible windings temperature is reached, so that the motor is switched off. For experimental reasons this motor winding protection was not used.

2.3. Measured Variables and Measuring Devices

The way in which the problem on which this investigation is based is posed, makes it necessary to measure different temperatures and pressures in the refrigeration cycle. The pressure measurements were executed with calibrated sensitive pressure gages. For the temperature measurements copper-constantan

-thermocouples were used in connection with special adapters.

2.3.1. Measurement of the Valve Clearance Temperature

The temperature measuring point T_2 at the valve clearance and the installation of the thermocouple into the discharge chamber can be seen in picture 2. The temperature pick up is inserted into the discharge chamber through the high pressure connection at the cylinder head of the compressor by using a gas-tight adapter and is positioned 1mm away from the discharge valve reed. This insertion guarantees a precise measurement of the discharge gas temperature T_2 on leaving the discharge valve.

2.3.2. Suction Temperature Measurements

To control the suction gas condition it is especially necessary to measure the initial inlet temperature T_1 of the refrigerant. Running the compressor in its orignal condition with suction gas cooling this happens right in the suction shut-off valve. If, however, the suction gas is fed directly into the suction chamber of the compressor, avoiding the electro-motor, the inlet temperature is measured in the suction chamber. For insertion of the thermocouples in the suction cut off valve and the suction chamber, adapters of the same type as those at the cylinder head were used. The comparison of the temperatures in the suction cut off valve and in the suction chamber makes it possible to deduce a statement on the heat dissipation from the suction gas cooled electro-motor.

2.3.3. Winding Temperature Measurement

In the case of suction gas cooling an inhomogeneous temperature distribution occurs in the windings of the electromotor, which is caused by the flow conditions. The insertion of the gage T_3 for the measurement of the winding temperature T_3 was made at a point where according to experience, it is most at risk from a rise in temperature. It is positioned on the side of the motor which is opposite to the suction chamber. There is no problem in the air-tight extension of the instrument leads out of the interior of the motor between the two seals of the bearing plate on the side of the motor.

2.3.4. Measurement of the Suction and Discharge Chamber Pressure

To complete the thermal variables of state, suction and discharge chamber pressures were measured with sensitive pressure gages. For this reason pressure gages had been joined to the gage connections of the compressor cut-off valves as well as to the suction chamber in the usual way. The high sensitivy of the gages guaranted a good reproducibility of the condensing and evaporating pressure, and thereby the corresponding temperatures, during measurements.

2.3.5. Recording of the Variables to be Measured

In order to be able to examine optimally the setting up and attainment of a stationary operation, the temperatures which were measured by thermo-elements were ascertained from a twelve point recording gage and recorded.
In addition to those temperature measurements which are described in 2.3.1. - 2.3.3. the stability of the temperature conditions at the heat exchangers was controlled by the recording of the gage.
An operating condition was considered to be stable in all those cases, where, after the adjustment had been finished, the recording gage did not show any fluctuation in temperature of more than ±1 degree over a period of one hour.

3. TEST PROGRAMME

The aim of the experiment was to investigate the influence of the heat generated by energy loss of the electrically driven motor on the temperature in the pressure valve clearance as well as on the temperature of the motor windings at evaporation temperatures below $-40^\circ C$ with the refrigerant R 502. In the refrigeration unit which has been described above, valve clearance and windings temperatures were measured at evaporation temperatures of between $T_o = -30 / -60^\circ C$ under the following conditions. There had to be a constant suction gas temperature of $T_1 = 0^\circ C$ = const. for the following condensation temperatures

1. $T_c = 30^\circ C$
2. $T_c = 40^\circ C$
3. $T_c = 50^\circ C$

when the refrigeration unit was operated in the following three ways

1. operation with suction gas cooling (original condition)
2. operation without suction gas cooling (direct feed of suction gas into the suction chamber)
3. operation with star circuit

As a nominal voltage for the supply of the electro-motor 380 V were used exclusively and checked for constancy.
The application limits, which were specified by a maximal admissible valve clearance temperature of $150^\circ C$ and a maximal admissible winding temperature of $100^\circ C$, had to be ascertained for each different mode of operation by varying the evaporation temperatures.

4. TEST RESULTS

The valves plotted by the temperature recorder were analysed in regard to the temperature of the motor winding, the valve clearances and the suction gas, the latter only to check the required suction gas condition of 0°C. It was impossible to analyze the recordings when switching the built-in motor to star curcuit within the range of low temperatures, as the winding temperature reached the application limit of 100°C within a very short period of time. The rise in temperature was, on average, 1°C in 1,25 sec. for all experiments.

The test results which were gained by analyzing the other experiments which were performed with direct flow into the suction chamber and suction gas cooling are reproduced in the diagramm shown in figures 3 and 4. Motor winding temperature and therefore valve clearance temperature are taken down in each case above the evaporation temperature serving as a parameter for a suction gas temperature of 0°C in case of a operation voltage of 380 V.

The diagramm representing the winding temperature (figure 3) shows clearly the influence of the suction gas cooling, which, because of a higher rate of flow through the motor at increasing evaporation temperatures leads to a decreasing winding temperature, though power consumption and heat loss are increasing.

The singular points at -60°C were received at an increased suction gas temperature of 5°C and 10°C respectively and were therefore not integrated in the course of the curve. Without suction gas cooling, operation above -40°C is not possible, as the winding temperature exceeds 100°C. The dispersion of the measuring points in those tests with a direct flow into the suction chamber is due to a lack of refrigerant flow in the electro-motor, which makes the conditions of heat transmission at the thermoelement ambiguous.

Because of the fall off in motor power consumption the winding temperature decreases with a falling evaporation temperature.

Therefore the winding temperature is in the admissible range if below -40°C. In this case it must be considered, however, that the operation limit can be shifted by excessive voltage. The diagram showing the valve clearance temperature (figure 4) demonstrates the known rise with falling evaporation temperature for suction gas cooling, i.e. with a higher pressure ratio but under proportionate.

With the refrigerant R 502 the operation limit is reached at -50°C, if the operating voltage is 380 V and if the condensation temperature is 50°C. With lower condensation temperatures but with the same voltage the valve clearance temperature stays below the operation limit. In this case it must also be considered, that the operation limit can shift with different voltages. Thus the valve clearance temperature is 10 % higher, for a still admissibly excessive voltage. The same applies if different refrigerants, e.g. R 22 are used.

For an operation without suction gas cooling the temperatures are on the whole lower and do not reach the operation limit. Having exceeded a maximum they even fall down towards lower evaporation temperatures. This means, that without suction gas cooling, operation is possible even with the lowest evaporation temperatures, without reaching the operating limit of the valve clearance temperature. In this range the motor winding temperature also decreases, so that there are not even restrictions on the use of lower temperatures in this respect. But as a direct suction is only possible below c. -40°C, because above -40°C, the winding temperature exceeds 100°C, it is necessary when cooling down to this temperature, to operate the compressor under suction gas cooling in order to keep the winding temperature within certain limits. Subsequently it is necessary to switch to direct suction, e.g. using an automatic pressure controlled valve in the suction line.

5. CONCLUSION

The following two methods were experimentally checked for their efficiency in extending the range of application

a) By-passing of the suction gas around the built-in motor

b) Switching the built-in motor over to star circuit with a lower winding current

The test results are as follows:

a) The operation limit, with the refregerant R 502 and with suction gas cooling and 380 V operating voltage at a condensation temperature of + 50°C, is - 50°C.

Above this temperature no direct suction is possible, because the motor winding temperature is too high For direct suction below -40°C the motor winding temperature is in the admissible range. The valve clearance temperature in this method decreases as well, so that the operation limit is no longer reached. In fact, it rather falls to lower temperatures after exceeding a maximum of -45°C to -50°C.

With lower condensation temperatures the

conditions are on the whole more favourable. With different refrigerants, e.g. R 22, however, the operation limit can also be reached.
Different operating voltages have not been investigated; with admissibly excessive voltage, however, it has been shown that, operation limits of the valve clearance temperature arise, which are about 10 % lower.

b)The switching over of the built-in motor to star circuit is connected with a quick rise in the motor winding temperature from about 1°C in 1.25 sec. and leads to a rapid attainment of the operation limit of 100°C.

The reason for this is the nearly constant torque consumption of the compressor, which, at a low voltage, causes a greater slip of the asynchronous motor, thereby a higher winding current together with a heat loss.

To sum up, it can be stated that method
a)namely switching over to direct suction in order to extend the range of application of a motor compressor is a suitable method below the operation limit,
whereas method
b)star circuit of the electro-motor is not at all suitable.

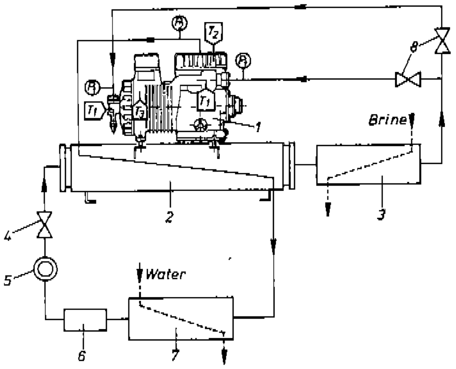

Figure 1 Test Arrangement

1 Compressor
2 Evaporator Condenser Unit
3 Heat Exchanger
4 Expansion Valve
5 Sight Glas
6 Filter Drier
7 Heat Exchanger
8 Valve

Ⓟ Pressure Gage
T Temperature Gage
P_1 Suction Pressure
P_2 Discharge Pressure
T_1 Suction Gas Temperature
T_2 Discharge Gas Temperature
T_3 Motor Winding Temperature

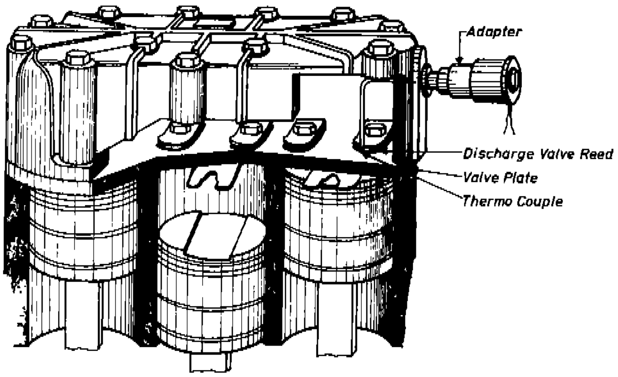

Figure 2 Discharge Gas Temperature Pick Up Arrangement

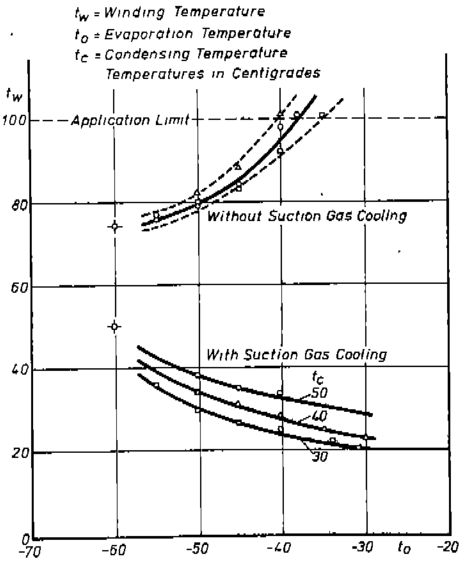

Figure 3 Winding Temperature t_w Versus Evaporation Temperature t_o

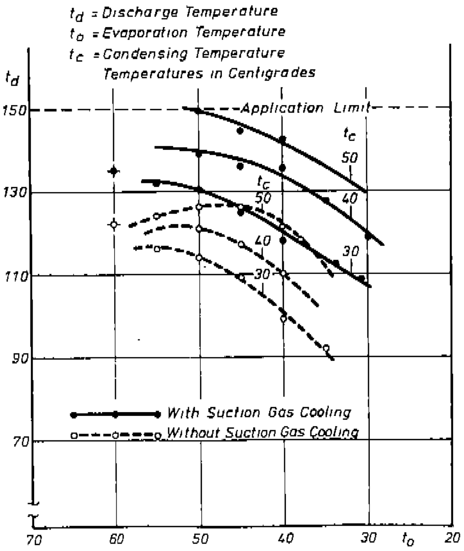

Figure 4 Discharge Temperature t_d Versus Evaporation Temperature t_o