Capacity cointrol for Refrigeration Systems

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Why and How to Use Capacity Control

The simplest form of capacity control is on-off cycling for the reciprocating compressors. Under light load conditions, this could lead to short cycling and could reduce the life of the compressor.

On systems where ice formation is not a problem, users will sometimes lower the low pressure cut out setting beyond the design limits in order to prevent short cycling. As a result, the compressor may operate for long periods at extremely low evaporator temperatures. Compressor capacity decreases as suction pressure decreases. Refrigerant velocity is inadequate to return oil to the compressor also resulting in a high compressor superheat, which causes the compressor to overheat. All of these conditions can cause pre-mature compressor failure.

Capacity control allows more continuous operation of the compressor, minimizing electrical problems and improving lubrication.

There are many ways to achieve capacity control. Variable speed compressors, hot gas bypass with or without liquid injection, unloading, Digital control for scrolls, and simple on/off compressor operation on multiple compressor setups.

Some applications will use two or more methods for smoother switching and better control such as unloading in conjunction with hot gas bypass.

It is acceptable fact that refrigeration systems seldom operate at the peak load for which they are designed. In any refrigeration application the load on the system varies over a wide range.

The refrigeration system designer has to however provide enough capacity to meet peak demand as well as some methods to make the system operate efficiently at reduced loads.

For example the loads in cold storage vary widely due to the fact that when product is loaded at ambient temperautre in cold rooms the amount of heat to be removed to bring the product to desired temperature in a given time is very high whereas once the product cools down to design storage temperature, the refrigeration load requirement reduces considersbly.The freezing plants may have varied equipments like IQF, Blast/trolley freezers, plate freezers to process variety of products but all equipment may not run simultaneously. In process plants the load may vary due to the fact that all processes may not be working at a time or peak output may not be required and products are produced in quantities to match market demands. The variation in ambient temperature conditions also affects the refrigeration load on systems.

When the system operates under partial load conditions, suction pressure and temperature are lower than they are under full-loaded conditions. This is due to the fact that less vapour is generated in evaporator due to reduced load, whereas the compressor running at constant RPM displaces a constant volume per unit of time. It does not recognize reduction in system load.

If the system capacity is in excess of load requirement, freezing of moisture on the evaporator coil may result. The "frost" on the coil decreases the amount of air that can pass through the coil, which in turn, lowers the suction pressure and temperature further. The excess un evaporated liquid may enter the compressor suction line and can cause damage to compressor parts.

It is also important to understand that the stabilized system capacity is determined by all the components working together in equilibrium and not by the compressor alone. The weakest/smallest component generally governs the overall capacity. Although the capacity is measured in terms of Btu/hr. or Kcal/hr or watts, the number of pounds/kgs of refrigerant circulating meaning mass flow rate determines the capacity.

The system that operates most efficiently, safely, and with the most stability will be the one that does best job of matching system capacity with load for the entire load range and each and every component of the system therefore has to have some means of capacity modulation to match the load.

For high, medium, and low temperature applications, compressor capacity modulation can reduce power and energy consumption; provide better & continuous dehumidification, reduce compressor cycling and decrease the starting electrical load and provide good oil return if properly piped.

Working of Compressor:

The refrigeration compressors used in ammonia refrigeration systems are of two types

Reciprocating compressors-open drive with external motor

Screw compressors-open drive with external motor

Both the type of compressors are classified as positive displacement machines which means increase in pressure takes place due to reduction in volume.

The reciprocating compressor for a given speed is a constant displacement volume, variable mass flow and variable compression ratio machine, whereas screw compressor has fixed internal compression ratio due to geometry of discharge port profile.

Riding with the load:

To a certain extent, the compressor automatically adjusts its capacity downward as system load decreases. A compressor running at constant speed displaces a constant volume per unit of time. For example a reciprocating compressor pumping 10cubic meter/hr is displacing a constant volume of $10m^3/hr$. As long as the compressor runs without any speed reduction or cylinder unloading, it will continue to displace gas at this rate.

Its capacity to transfer heat, however, is determined by its **mass** flow rate. That is its capacity to move heat depends upon how nay kgs of refrigerant (the mass) it pumps per unit time (kg/hr) and not on how many cubic meter of refrigerant it moves per unit time (m^3/hr). The mass flow rate changes depending upon suction or inlet pressure conditions. This means that while the volume flow rate is constant capacity will change with changing operating conditions.

For example Ammonia compressor having saturated suction temperature as 5^0C has specific volume of vapour as $0.243m^3/kg$. It means the mass flow rate would be 41.15 kg/hr.

When the load reduces the suction pressure drops. Let us consider that it drops to 2^0C. The specific volume then is $0.27m^3/hr$, and the mass flow rate therefore is $10/0.27= 37m^3/hr$. It can be thus observed that compressor has automatically adjusted to reduced load by pumping lower mass (kg/hr).

Now let us consider that the load increases and the suction pressure increases to SCT 10^0C . the specific volume now is $0.206\ m^3/kg$ and the mass flow rate would be 10/0.206= 48.54 kg/hr, indicating that the same 10 cum displacement compressor is now pumping more mass of 48.54 kg/hr instead 41.15 kg/hr at 5^0C saturated suction conditions.

If floating with the load as indicated above satisfied all necessary capacity adjustments at part load, then controlling the capacity of compressor would not be necessary. However, there are limitations as to how far the load can vary while maintaining safe stable part load operation while maintaining efficiency. Maintain constant suction pressure as designed would lead to better efficiency at all part load conditions and hence some methods of capacity control are necessary.

To discuss compressor capacity control systems so that the load and output from refrigeration system are matched it is necessary to briefly look at how the compressor works

The refrigeration compressor circulates refrigerant in the system. The compressor takes in low pressure, low temperature, and superheated refrigerant gas after it has done its work of picking up heat in the evaporator where liquid refrigerant gives up its latent heat and gets converted in gas. This gas is compressed by compressor to a high pressure and high temperature, superheated gas and sufficiently high enough temperature so that it is able to reject heat to condenser, where refrigerant is condensed back in to a liquid.

The compressor manufacturer cannot determine the system capacity. All that a refrigeration compressor can do is to pump a volume of gas. Once the suction and discharge conditions at the compressor are specified, then the mass flow of refrigerant can be calculated. But the refrigeration capacity is not related directly to the conditions at the compressor. The system designer should ask for the mass flow rates at specified conditions in order to get correct selection of the compressor from manufacturer. The designer must accept that when they buy a refrigeration compressor it pumps only a volume of gas, and not refrigeration capacity.

Capacity control methods for various types of compressors:

We shall now discuss capacity control arrangements for compressors for optimum system performance.

Reciprocating Compressors

Following strategies are generally adopted depending upon the size of plant, accuracies required, degree of automation and other considerations

1. **Use of multiple compressors**- Rack systems-Depending upon the load compressors are cycled on/off and leads to a great extend power reduction. Each compressor is of max.20 ton capacity ared racks can be build with 4 or 5 compressors.
2. **Hot gas bypass arrangement with or without liquid injection**: This arrangement ensures that compressor does not trip on suction pressure when system load is extremely low, below the compressor minimum capcity control step. The artificial load is imposed by high preesure hot gasin the suction line or before the evaporator entry. The disadvantage of this system is if the compressor is overdesigned the period of compressor operation on hot gas bypass circuit is too long and compressor wear out is faster. Also running on hot gas by pass deos not lead to power saving.
3. **Two speed compressors**- Normally used in semihermatic compressors. The speed is changed in response to a thermostat or pressure signal. When initial load is high one can run the compressors at higher speed with 2 pole motor and when the load comes down and the requirement is holing load, one can switch to 4 pole windings so that speed is reduced to half from 300 RPM to 1500 RPM
4. **Use of VFD drives/Speed control**: This solution is applicable fro all types of compressors. And is efficient method.The VFD costs have come down substantially and it is now arttractive to use variable drive to compressors. The advantage being during initial cool down when load is high one can run the compressors with 60/70 HZ frequency for a short duratiion to get higher capacity and then match the capacity to load requirement by sensing either suction pressure or if it is fluid , the sensing the temperature. The frequency converter thus can vary the rotational speed continuously to satisfy the actual laod demand. The other advantage of frequency converter is it allows low start up current.The limitation being one cannot exceed allowable lower and higher speed limits of compresors especially reciprocating as the likelihood of suffering from inadequate lubrication. In screw compressors wher independant oil pump has been provided and lubrication circuit is not dependant on compressor RPM, VFD's are preferred options.

5. **Step Control:Cylinder unloading in multicylinder compressors:**

   The capacity of these compressors is regulated by means of a valve lifting mechanism.

   As soon as the compressor starts running on fully unloaded condition, the high pressure oil pump begins to develop oil pressure and after set time delay the high pressure oil is delivered through three way solenoid valve to valve lifting mechanism and the cylinders get loaded. The arrangement of loading or unloading the cylinders defers from manufacturer to manufacturer. Some manufacturers use compressed gases instead oil pressure to load the cylinders.

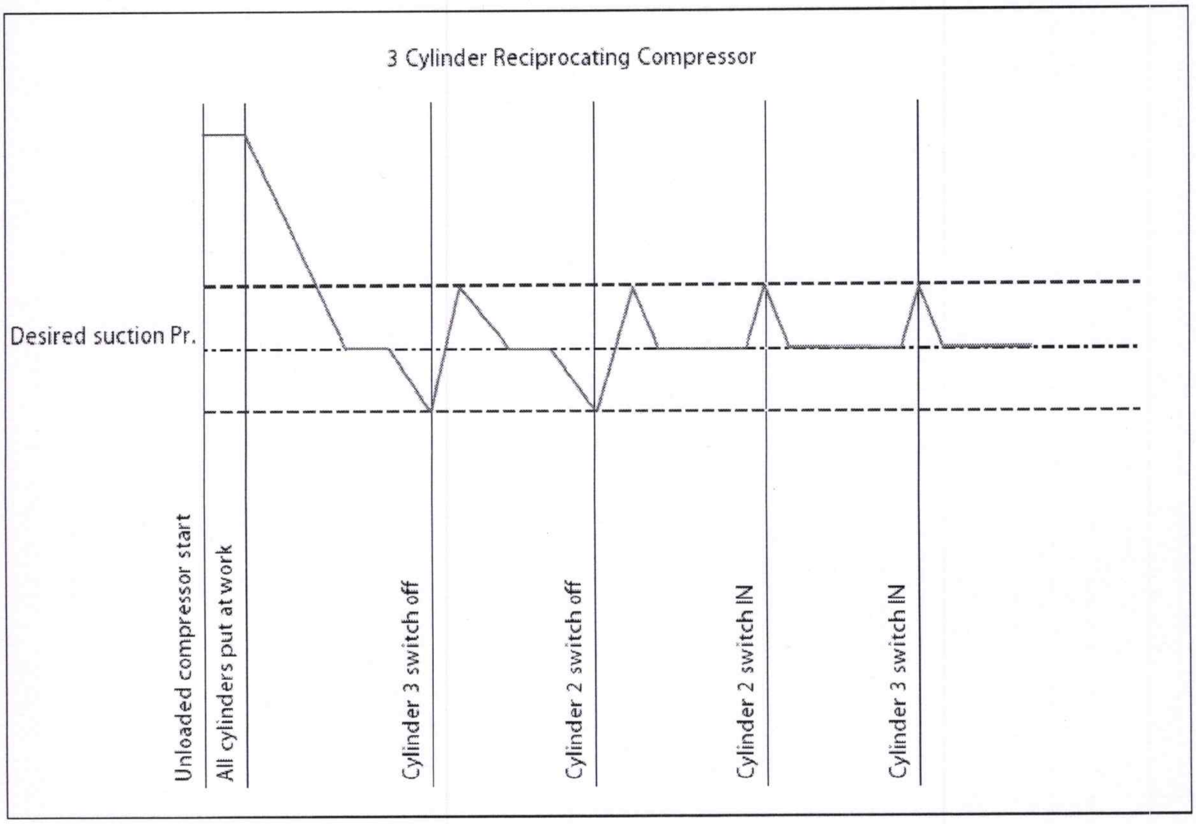
The cylinders can be switched in or off in different ways:

a. By means of pressostats or thermostats
b. By means of modutrol motor and a pressostat with floating regulation
c. By means of modutrol motor with modulating pressostat or thermostat.
d. By means of modutrol motor, an electronic regulating panel and resistance thermostat.

In refrigeration plants , using several compressors on common suction line or using single compressor with multiple capacity control steps through 3 way solenoid valves, a suction pressure transmitter is preferred where as for applications using chilled water or brine signal from thermostat can be used.

The pressostat fitted in the suction line carries a contact on both sides of its neutral middle position. When pressure gets too high due to increase in load requirement, the contact

The diagram below shows the sequence of cylinder loading and unloading in case of a typical 3 cylinder reciprocating compressor.



Screw Compressors -Capacity Control

Screw compressors unlike reciprocating compressors do not have suction and discharge valves. They have what is called a built-in volume ratio. Vi is the volume ratio of volume at the rotor groove pair at the beginning of the compression and volume of the same rotor pair grooves at the end of the compression at the out let.

Volume ratio (Vi) is the same ratio of discharge pressure to suction pressure since volume ratio is also related to pressure ratio. In most of the screw compressor designs, the Vi by design and selection of particular model is fixed unlike reciprocating compressors, where Vi is constantly changing automatically, the reason being for given Vi, the discharge port pressure is fixed irrespective of the condensing pressure imposed by the system.

For screw compressors, two forms of variable volume control are available

1. Adjustable volume ratio (Vi)
2. Automatic variable volume ratio (AVi)

Care is taken during compressor selection to ensure that the correct volume ratio is selected by comparison to the chosen operating conditions, however, in many instances the compressor is selected for peak conditions which apply only for few days in a year.

While it is essential to select compressor which is capable of operating in the extreme conditions, it does not follow that the compressor will necessarily always perform at the highest possible efficiency.

The variable Vi concept, coupled to slide valve, which moves parallel to the axis of rotors, offers alternative method of controlling capacity and volume ratio to suit site conditions.

Where the pressure ratio across the compressor is consistently high or changes in pressure ratio are infrequent (e. g. change from winter to summer) then MVi manually adjustable system which is economical will work satisfactorily.

Where the pressure ratio is lower and where condensing conditions vary frequently, the automatic AVi system is ideal.

The system works as under

The compressor is fitted with a built in sliding valve which controls the capacity of the machine by altering the point on rotor length at which compression begins. The slide valve moves along the axis of the rotors. The slide valve can be operated either manually or automatically; by hydraulic actuator.

The position of slide valve ensures that the discharge pressure of the compressor is equal to the system pressure, thus over or under compression which leads to system inefficiency and excessive power consumption, is eliminated.

When partial load operation is taking place, a signal is provided by the microprocessor and the slide valve is adjusted to allow partial gas bypass to the suction side, delaying the compression and reducing the suction volume. As the suction volume is reduced, in part load, in order to maintain the discharge port pressure, the discharge port area is also reduced by moving the slide valve.

The oil pressure for the hydraulic actuator is provided from the compressor oil system and the solenoid valves responding to suction pressure or air/fluid temperature through microprocessor energize/de-energize leading to movement of slide valve. This movement of slide valve in response to evaporator load, is by different mechanisms in different screw compressor designs such as an electric impulse motor or a linear variable displacement transducer-operating through hydraulic piston. Control down to 10% with approximately proportional saving in power is obtained.

It can be thus seen that screw compressor control through unit's microprocessor, the system provides very accurate control at maximum efficiency at all operating conditions, providing capacity control from 100 to 10% is possible but the efficiency drops at part load.. The power consumption below 50% capcity however is not reduced linearly and therefore running screw compressors below 50% capcity is not economical.

Some manufacturers have developed multistage control system which functions similar to slide valve control.

The control unit comprises of hydraulically operated pistons, which at full load operation form fit with the end flange. The pistons open when the pressure in the crankcase is above the normal operating pressure which is usually the oil/condensing pressure. Thus automatic start unloading is guaranteed and also protects against abnormal high discharge pressure or over compression.

In part load operation, it is two step capacity control. The piston moves due to energizing of solenoid valve in two steps controlled by either time delay or on demand control and is adjustable to suit exact load. When the solenoid is de-energized, the piston moves to the right and thus causes space to be opened up between profile chamber and suction side thus reducing active volume. The system is designed for two control steps, so that through the intermittent switching of the solenoids valves it is possible to achieve exact match of compressor capacity with load. The step is 70% of the capacity (0-75%-100%)

capacity control for Cetrifugal Compressors:

Guide vane control: The inlet guide vanes rotate with motorized control sensing the load requirement. When vanes close the amount of gas admitted is reduced and thus contineous capcity reduction is achieved. The lower limit of capcity is avoiding suge point as specified by the nmanufacturer.

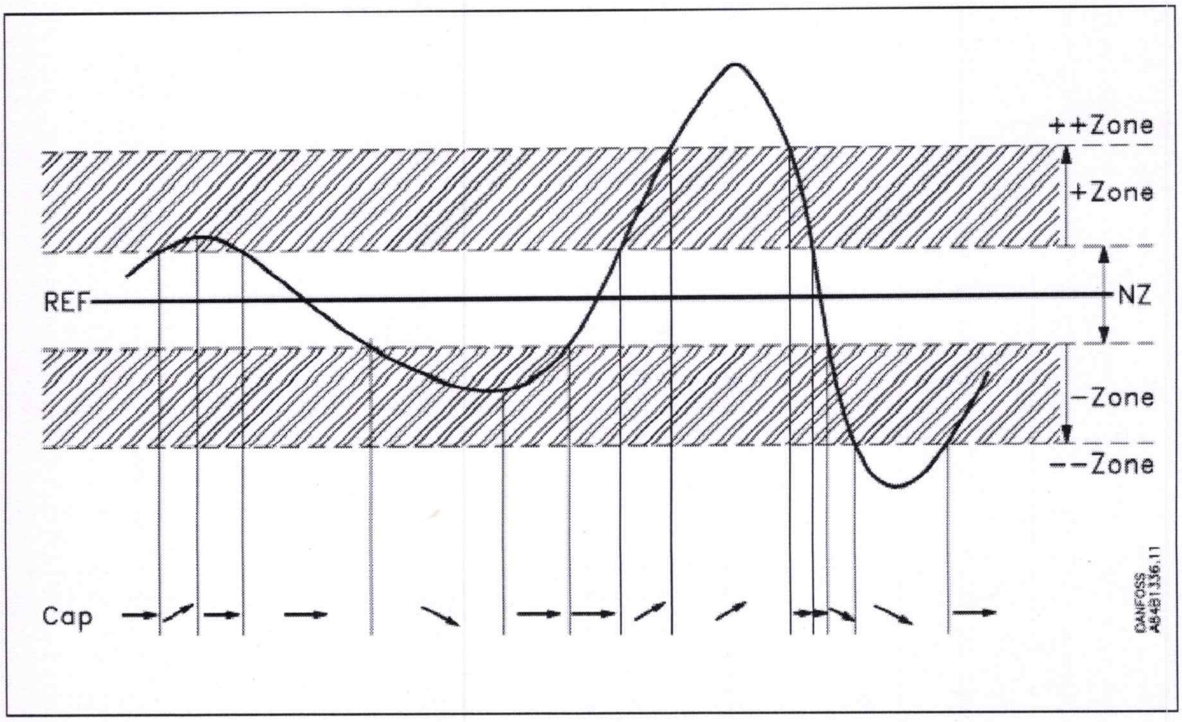
Danfoss Capacity Controller AK-PC 530:

Danfoss uses AK-PC 530 capacity controller for the purpose of capacity control of reciprocating compressors. A number of compressors and condensers can be connected as required. There are up to eight outputs and more can be added via external relay modules. For the operation of this controller display type EKA 164 or EKA 165 has to be connected with this controller.

Function :

Capacity regulation

The cut-in capacity is controlled by signals from the connected pressure transmitter/temperature sensor and the set reference. Outside the reference a neutral zone is set where the capacity will neither be cut in nor out. Outside the neutral zone (in the hatched areas named +zone and -zone) the capacity will be cut in or out if the regulation registers a change of pressure "away" from the neutral zone. Cut in and cutout will take place with the set time delays. If the pressure however "approaches" the neutral zone, the controller will make no changes of the cut-in capacity. If regulation takes place outside the hatched area (named ++zone and --zone), changes of the cut-in capacity will occur somewhat faster than if it were in the hatched area.

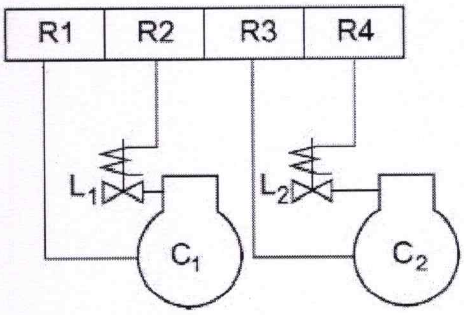


Cutin of steps can be defined for either sequential, cyclic, binary or "mix & match" operation.

Sequential (first in - last out) :The relays are here cut in sequence – first relay number 1, then2, etc.Cutout takes place in the opposite sequence, i.e. the last cut-in relay will be cut out first.

<u>Cyclic (first in - first out)</u> :The relays are coupled here so that the operating time of the individual relays will become equalized at each cut in the regulation scans the individual relays' timer, cutting in the relay with least time on it. At each cutout a similar thing happens. Here the relay is cut out that has most hours on the timer.

If capacity regulation is carried out on two compressors with one unloader each, the following function can be used: Relays 1 and 3 are connected to the compressor motor. Relays 2 and 4 are connected to the unloaders. Relays 1 and 3 will operate in such a way that the operating time for the two relays will become equalized. Similar logic is applied for more than 2 compressors having each having more than one un-loader each. Please refer to the table for details.

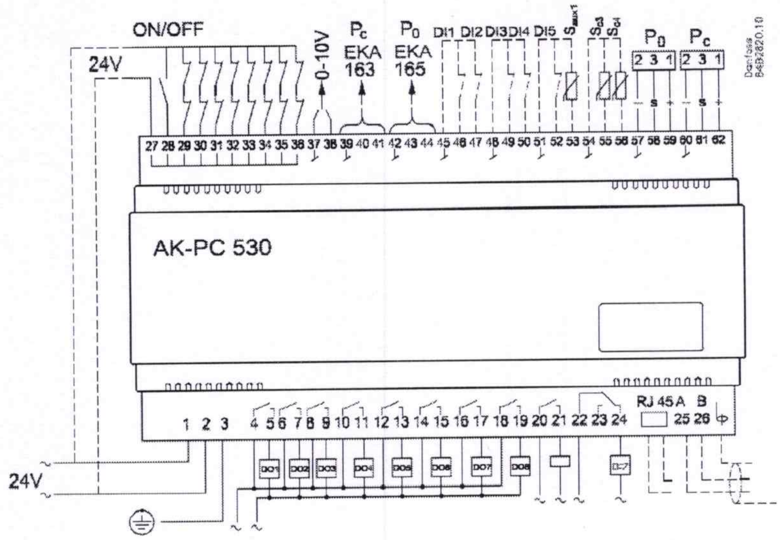


Compressor connections

Relay no.

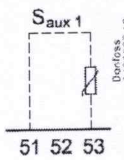
1	2	3	4	5	6	7	8	9	10
1									
1	2								
1	2	3							
1	2	3	4				Binary		
1	1a								
1	1a	1b							
1	1a	1b	1c						
1	1a	2	2a						
1	2	3	4	5					
1	2	3	4	5	6				
1	2	3	4	5	6	7			
1	2	3	4	5	6	7	8		
1	1a	1b	2	2a	2b				
1	1a	1b	1c	2	2a	2b	2c		
1	1a	2	2a	3	3a				
1	1a	1b	2	2a	2b	3	3a	3b	
1	1a	2	2a	3	3a	4	4a		
1	1a	2					4 x 25 %		
1	1a	2	3				6 x 16,6%		
1	1a	2	3	4			8 x 12,5 %		
1	1a	1b	2				6 x 16,6 %		
1	1a	1b	2	3			9 x 11 %		
1	1a	1b	2	3	4		12 x 8,3 %		

Connections



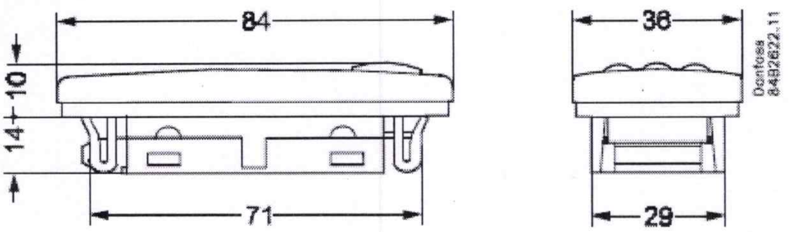
P0/Pc: AKS 32R:
1 = Black = +
2 = Blue = -
3 = Brown = s

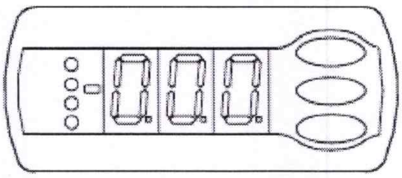
Compressor control
with temperature



o06 = 0
o81 = 1
Other combinations: see page 21

All inputs are low-voltage.
All relay outputs may be
high-voltage.





Only for front mounting (IP 40)
Only connection via plugs

Display type EKA 163 / EKA 164

Ramesh Paranjpey 16-10-12