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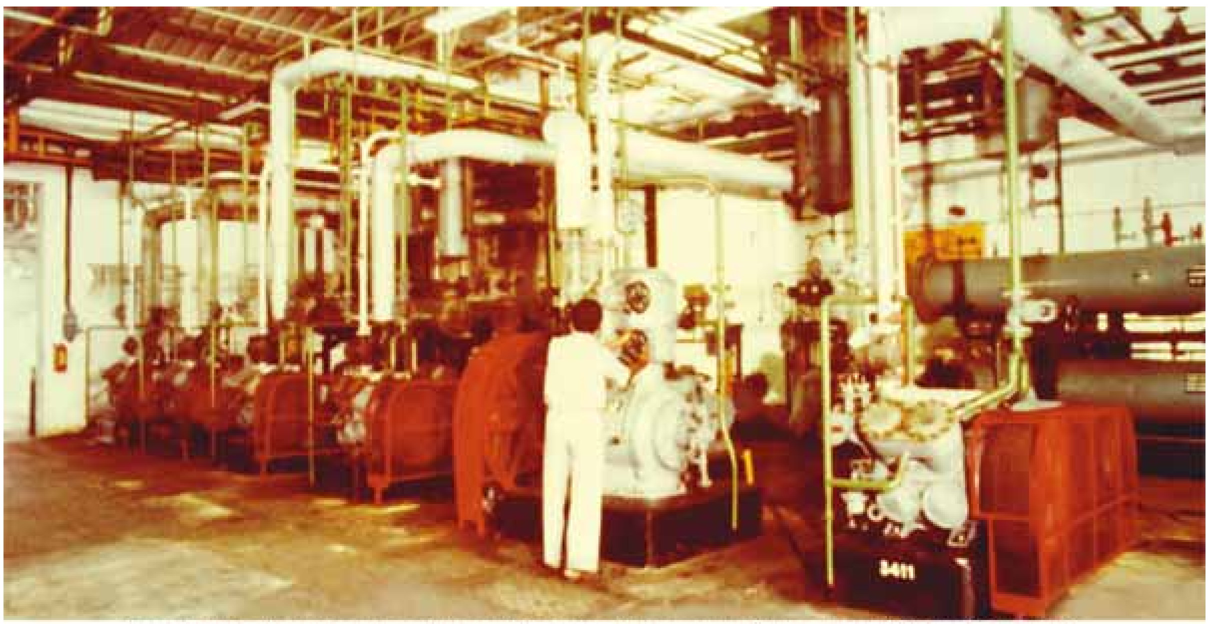

General view of refrigeration system plant room with reciprocating compressors. *Photo courtesy of Kirloskar Pneumatic Co.*

Faster Pull Down in Refrigeration Plants

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When designing low temperature refrigeration plants involving twostage compressors, it is necessary to determine, in advance, the pull-down period

required by the client so that equipment such as motors, condensers, pumps, cooling towers are adequately sized.

Several years ago at a Paper Mill in south India where I was commissioning a low temperature brine chilling plant supplied by our company, the chief engineer complained that the plant was taking too long to achieve the desired low temperature. When I pointed out to him that he had never specified the pull-down period required, he realised his mistake and did not repeat it on his next project, which was also awarded to our company.

Pull-down is the process of reducing the standstill temperature either of brine/water or of the surrounding space to the desired design temperature or to comfort conditions in case of air-conditioning. The initial standstill conditions are those of the ambient surrounding the process or the space or room to be conditioned. When the refrigeration or air-conditioning unit is started, it starts reducing the temperature almost instantaneously but the load on the system is very large compared to the cooling capacity of the unit provided.

It is expected that the unit will achieve the desired final design temperature as soon as the unit is switched on. Manya- times the unit has to be started at least an hour or two before the space is to be occupied by the participants. The secretary starts the A/C unit at least half-an-hour in advance before the boss arrives. This has to be done so that the inside temperature comes down to a comfortable level even if it is not the final desired level.

During the initial start, the load is very high since the ambient is high. The compressor will start at the highest evaporating temperatures of say +5°C or +10°C or even higher. This will give the highest capacity of the compressor and will also need the highest power input. The motor can get overloaded and if the motor can take up the load by drawing higher current, the condenser will get overloaded, proper condensation will not take place, no subcooling can be expected and some flash gas can enter the expansion valve.

In order to overcome the above problem, it is generally a good practice to include some kind of Motor Load Control (MLC), a device which controls the % of full load amps (FLA) of the motor irrespective of the actual load demand. This is normally a standard control in most centrifugal and screw chillers used in air-conditioning applications. If you set the MLC at 80% at the starting time of the plant, the motor cannot draw more than 80% of the design FLA (not necessarily the motor FLA since the motor is invariably oversized for various reasons) and then the complete unit cannot get overloaded. This MLC setting can be increased to 100% once the initial pulldown load has been achieved.

Air Conditioning and Refrigeration Plants

The pull-down conditions are applicable to both air conditioning and refrigeration plants. But it is much more severe in the case of refrigeration plants, due to the low temperatures involved. For low temperatures, invariably two-stage compressors are required. There are some special precautions and even changes in the piping and design that are required to achieve a faster pull-down and an attempt is made in this article to help the reader take proper steps, either at the design stage or even in the field, at a later stage, to avoid such problems.

Low Temperature Refrigeration Systems

Low temperature systems require multi-stage compressors, since the compression ratios are much higher than the capability of a single stage design. In case of booster systems where two or more single stage compressors are involved, the pull-down problems are not as severe as in the case of compound compressors. Hence this article will go into more details for compound compressor systems.

In a reciprocating compound compressor (two stages of compression in one compressor frame or body), it is possible to go down to about –60°C evaporating at a condensing temperature of about +40°C with common refrigerants such as R-22 or R-717. The intermediate pressure of such compound systems is Generally $Pm = \sqrt{Pc \times Pe}$, where Pm = the mean pressure or the intermediate pressure and Pc=condensing pressure and Pe=evaporating pressure. A typical compound compressor rating table for Ammonia is shown in **Table 1** for the most common condensing temperature of 40°C and two compressor models discussed in this article.

Table 1 : Typical K-110 compound compressor ratings with Ammonia at 750 rpm.
(extracted from the complete table)

		K 40.20 × 110			K 100.20 × 110		
t °C	t_o °C	t_m °C	Q_o kcal/hr	N_e pk*	t_m °C	Q_o kcal/hr	N_e pk*
	– 20	+ 02.0	142600	88.6	+ 27.0	312500	192.5
	– 25	– 03.0	113000	80.0	+ 19.5	244800	172.2
	– 30	– 09.0	88000	70.8	+ 12.5	189600	151.6
	– 35	– 14.0	67400	62.4	+ 05.5	145000	132.1
+ 40	– 40	– 19.0	(50800)	53.7	– 01.0	109200	112.9
	– 45				– 08.0	80000	96.1
	– 50				– 14.0	58200	81.1
	– 55				– 19.5	(42000)	68.1
	– 60				– 24.5	(28600)	57.1

- When values have been placed between brackets () isentropic discharge temperature exceeds 120°C.
- Capacity values placed within a border MUST NOT be used, because of unfavourable performance.
- Capacity and power consumption are proportional to speed. Minimum permissible speed : 400 rpm.

pk* = Metric Horsepower

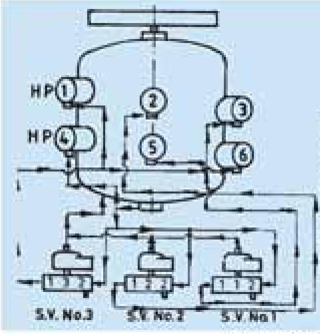
Two - Stage KC Compressors

The two-stage KC compressors are available from the smallest KC-21 to the largest KC-102 or KC-93 or KC- 84 models. The last digit in the model shows the number of cylinders in the HP and one or two digits on the left side of the last digit show the numbers of LP cylinders. Thus model KC21 has two LP and one HP cylinder and model KC 102 has 10 LP and 2 HP cylinders. There are various standard steps of capacity control with various models. These steps can be changed to some other combinations as well, subject to some standard ratios of LP to HP cylinders.

A typical example of KC42 and KC102 are shown in **Figure 1** and **Figure 2**.

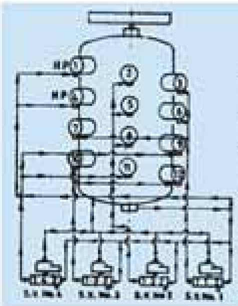
$$\text{The ratio } \varnothing = \frac{\text{No. of LP cylinders in operation}}{\text{No. of HP cylinders in operation}}$$

The combination of LP & HP has to be such that the working of the compressor will be balanced. The ratio Ø can vary from 1.5 to 5. "Field application diagram" for these compressors is shown in **Figure 3**.



	CY. BLOCK NO.						CAPACITY	Ø
	1	2	3	4	5	6	%	
DIRECT CONNECTION	–	–	–	✔	–	–	–	–
SOLENOID VALVE 1 ON	–	–	✔	✔	✔	–	50%	2
SOLENOID VALVE 2 ON	–	✔	✔	✔	✔	–	75%	3
SOLENOID VALVE 3 ON	✔	✔	✔	✔	✔	✔	100%	2

Figure 1 : Two-stage compressor KC-42.



	CY. BLOCK NO.												CAPACITY	Ø
	1	2	3	4	5	6	7	8	9	10	11	12	%	
DIRECT CONNECTION	✔	–	–	✔	–	–	–	–	–	–	–	–	–	–
SOLENOID VALVE 1 ON	✔	–	✔	✔	–	✔	✔	–	–	–	–	–	30%	1.5
SOLENOID VALVE 2 ON	✔	✔	✔	✔	✔	✔	✔	✔	–	–	–	–	60%	3
SOLENOID VALVE 3 ON	✔	✔	✔	✔	✔	✔	✔	✔	–	✔	–	✔	80%	4
SOLENOID VALVE 4 ON	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	100%	5

Figure 2 : Two-stage compressor KC-102.

If we consider the model KC 42 and standard steps of capacity control @ 50%, 75% and 100% as shown in **Figure 1**, the values of Ø are 2,3 & 2 for Solenoid Valve 1, Solenoid Valve 2 and Solenoid Valve 3. If we use the **Figure 3** for NH_3 @ –30°C evaporating/+ 40°C condensing, we can see that the 1st Solenoid Valve cannot be put on till we reach the evaporating temperature, of about –12°C and second step with Solenoid Valve 2 (Ø=3) cannot be loaded until we reach evaporating temp. of –22°C. The 3rd Solenoid Valve for 100% capacity can be loaded soon after step 2.

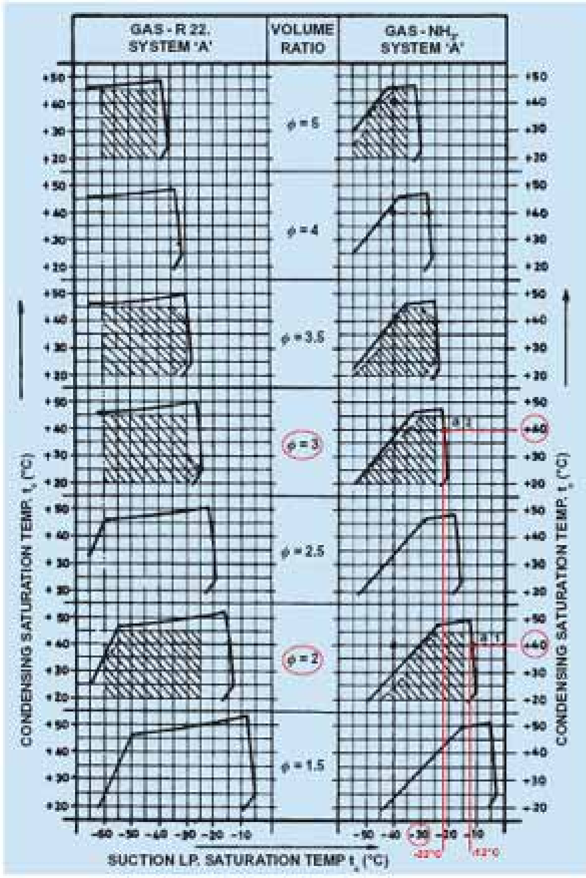


Figure 3 : Field application diagram.

Pull-Down

From the example explained above, we can see that the two-stage compressor KC42 will work as KC- 1, a single stage compressor till the temperature comes down to a minimum of –12°C. This means that the KC42 although a six cylinder compressor, will only work as a single cylinder KC-1 compressor and the capacity and power consumption of the same will be half of the KC2 model at the highest evaporating temperature of +5°C or +10°C as shown in the performance table of KC2 ratings.

If the system is designed for a brine chilling application and if the brine tank is of large size, thereby having a large mass of brine in the system, then it will take several hours or even days for the initial pull-down till it can be loaded as a two stage compressor. The time taken can be very long and if this type of pull-down is to be encountered more frequently, every time the same amount of long-time intervals will have to be faced. Similarly, in the case of batch type of blast freezing where the temperature of the product has to be brought down to say –30°C or –40°C in an 8 hour period, and if the initial pull-down itself takes 4 to 5 hours, then we will not be able to achieve this freezing process in the stipulated time slot. The same becomes applicable in the case of cold storage applications where the initial product load is too high and it may take several days to achieve the desired low temperature of –12°C to –15°C, before putting the full compressor to use.

Faster Pull-Down

To overcome the problem of slow pull-down taking a very long time of several hours or several days, a solution can be worked out. This solution needs careful technical considerations. If one can foresee the need for such a faster pull-down, in advance, then the same can be implemented very easily.

Depending upon the requirements of the situation, we can decide if we want to operate the KC42 as KC1, KC2, KC3 or KC6, as a single stage compressor, during the pull-down conditions. Let us consider a case where the boundary conditions and other parameters dictate to us that it should be used as a KC- 4 single stage before converting it into a two-stage KC42 unit. The compressor will operate at the same design speed selected, whether it operates as a single stage or two-stage and hence all calculations will be based on the same speed.

Let us consider the selected speed as 1000 rpm. If a KC4 @ 1000 rpm operates at +10°C / +40°C it gives 581,900 kcal/hr (192.4 TR) and consumes 104.1 kW. The motor will be selected for 104.1 x 1.1 = 114.51 kW and the next standard size, 125 kW will be used. The condenser has to be designed for THR (total heat rejection) = 581,900+104.1×860 = 671,425 kcal/hr a total heat of rejection of 671,425 kcal/hr. Similarly the oil separator should also be selected for KC4 capacity and not for KC2, in the KC42 model.

The loading of the compressor to KC4 has to be done only manually. To achieve this, we have to load Solenoid Valve 1 and Solenoid Valve 2 manually so that the compressor operates as a single stage KC4 compressor with cylinder Nos. 2,3,4 & 5 in operating conditions. In addition to manual operation of the Solenoid Valve 1 & 2, we have to close the shut-off valve in the interstage piping V1 as shown in **Figure 4** and open the valve V2. This will prevent low stage vapours going to HP suction and instead go directly to discharge, since it is acting as a single-stage machine.

If for any reason, we want to use all the 6 cylinders as HP single stage, then effectively, an additional suction strainer will need to be installed for suction to the HP two cylinders by opening valve V3.

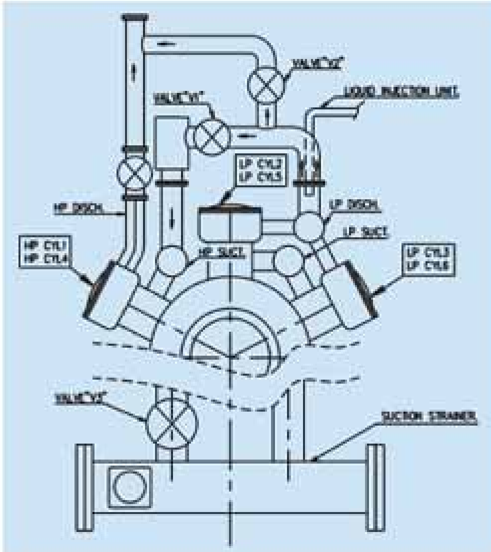


Figure 4 : KC-42 working as KC-4.

This is shown in **Figure 5.** In such a case, the condenser, the motor, the oil separator etc. have to be designed for KC-6 capacity of 872,800 kcal/ hr (288.6 TR) and 155kW power consumption at +10°C/+40°C at 1000 rpm. In such a case, the design of the condenser for proper higher water flow, pump selection, water velocity in the condenser tubes, refrigerant piping selections for velocity range etc. have all to be cross-checked.

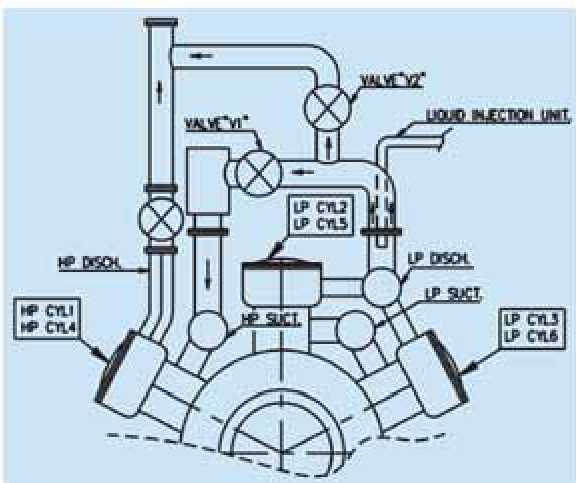


Figure 5 : KC-42 working as KC-6.

Two-Stage Operation

The various standard steps of capacity control are as shown in **Figure 1** earlier. The compressor KC42 starts fully unloaded, and then with the hydraulic delay, HP cylinder No.4 will get loaded automatically. This is KC1. The next step with Solenoid Valve 1 'on' it becomes KC21. With Solenoid Valve 2, it becomes KC31 and with all Solenoid Valves 1,2,3 'on', it becomes KC42. It is necessary to calculate the condenser and motor loads in all these steps and choose the highest of these for proper condenser and motor sizing. If this is not done, they will get undersized and become overloaded.

All the considerations of refrigerant pipe sizing selections etc. as enumerated in the earlier paragraph are applicable here also and generally it is sufficient if designed for KC42 in the final stage, but it is better to cross-check for intermediate steps of capacity control as well.

Whenever, you want to switch over from manual operation of faster pull-down, to normal twostage operation, it is necessary to undo the manual operation of solenoid valve to automatic operation as well as opening of Valve V1 and closing of Valve V2 and or V3 etc. as explained earlier.

Starting of two-stage compressor and loading of compressor from unloaded start to 100% load, is to be done very carefully, otherwise the discharge temperature and pressure of the compressor will exceed beyond the limits of operation, resulting in a failure or breakdown of the compressor.

Fixing of valves V1, V2 or V3 can be done at the factory itself if the requirements and extent of faster pull-down are clearly understood by the customer and the dealer or contractor. If it is not known before hand, and is only realised in the field, after the system is commissioned (which is the more common occurrence) then one has to consider the existing parameters before deciding the extent of faster pulldown possible.

Changes for Achieving Faster Pull-Down in the Field

If the need of a faster pulldown is not realised or understood by either or both the customer and the dealer/seller, then it is not possible to redesign the complete system and change all the major components such as motor, condenser, pumps, oil separators etc in the field. In such situations, one needs to study the built-in safeties and oversizing provided in the design and calculate in a reverse manner as to what is the extent to which the faster pull-down can be achieved. Generally it is possible to use one or two steps higher i.e. instead of KC1 in the HP stage, it may be possible to go upto KC2 or KC3 at the most for a single stage operation in the KC42 case considered. Generally condensers are designed for 10% safety factor. But this has to be checked. If the bid has to be very competitive it may have only 5% or 0% safety factor. Similarly, the oversizing of motor is to be checked. Generally at least 10% or normally 20% motor oversizing is recommended for low-temperature applications, on the final operating conditions. Apart from this intentional oversizing, the motor gets much more oversized due to standard sizes of motor availability.

In addition to this, a motor can inherently withstand about 15% more amperage drawing capacity due to the basic service factor built into the motor design by the motor manufacturer. Similarly the built-in excess gpm capacity of condenser water pump and motor has to be checked, as we will need more cooling water for faster pull-down. Only by studying all these technical parameters, can one decide the extent of faster pull-down possible. Apart from this, the inclusion of valves V1, V2 and / or V3 has to be done in the field for which a shut down will be required.

Conclusion

Faster pull-down is a very important consideration, more for low-temperature refrigeration jobs although it is also applicable for other jobs including air-conditioning. Most of the time, the seller is not aware of a customer's needs of frequent or batch type operations or the time period of pull-down, brine reservoir capacities etc. and the customer is not in a position to spell out these as he is totally ignorant of such parameters. One often ends up in realising this only after the system is commissioned and handed over. In order to avoid these types of frustrations or traps it is necessary to discuss these requirements with the customer to avoid problems at a later stage. This article will help in identifying the correct needs for a specific application.

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