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Selection and Application of Industrial Screw Compressors

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SELECTION AND APPLICATION OF THE INDUSTRIAL SCREW COMPRESSORS

Stationary Electric-Driven Packaged Screw Air Compressor

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I. INTRODUCTION AND DEVELOPMENT

The rotary screw compressor is new in the United States but its early development began a long time ago in Europe and parallels the development of the diesel engine. The first patents were taken out in Germany in the 1880's and most of the developments have occurred in Europe.

In the 1930's a Swedish inventor, Alf Lysholm, patented the screw compressor similar to that manufactured today. However, its development was hindered by the very difficult machining job and the special tooling required to cut the rotors. Finally, an English company, the Holroyd Corporation, designed a milling machine for rotors and mass production was made possible. Various European companies manufactured the screw compressor for special applications throughout the '40's and a few machines were made in the United States in this period. However, it was not until the late 1950's that serious production began in the United States. Now there are at least six U. S. A. manufacturers plus those who are importing units made in Japan and Europe. All evidences are that the screw compressor has found a firm place in the American market and is here to stay.

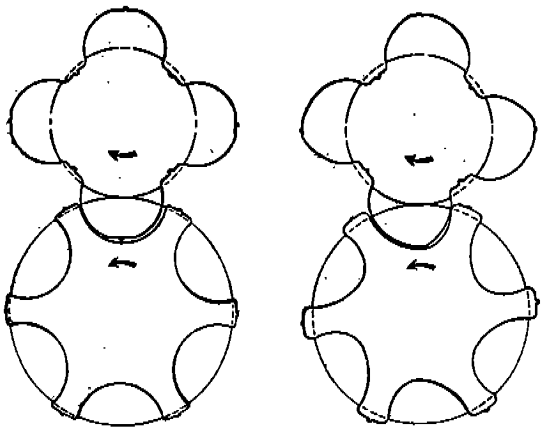
II. BODY - THE PACKAGED COMPRESSOR OF TODAY

Although the early compressor manufacturers in Europe and the United States manufactured just the compressor, and the accessory items could be supplied by the user or an engineering construction firm, it soon became apparent that for successful operation and for simplicity in sale and installation that a complete package system was desirable. Practically all the suppliers of the screw compressor today make a complete package. For analysis and study we will study the package in its component parts -- first the compressor alone, second the accessories required with the package, and thirdly the controls available.

A. The Compressor Itself

Although practically all the screw compressors are made to the Swedish patents, there are some rather wide choices to be made on the units now being manufactured. The first basic selection is whether the unit is to be a dry screw compressor or an oil-flooded screw compressor. The dry screw compressor was developed first with rotors that do not touch but are separated by timing gears attached to the male and female rotors. The very close fit of the rotors in the stator and rotor to rotor reduces but does not eliminate slippage and, therefore, the performance characteristic is a combination positive displacement and dynamic type. The speed of the rotors is kept high to compensate for the leakage. The dry screw compressor has the advantage of producing oil-free air; and also the dry screw compressor has found a spot in the process industry and is particularly good for handling low molecular weight gases. On these applications the special carbon ring face seals are required to prevent leakage and are slight detractors from efficiency because four seals are required and each absorb power. The oil-flooded compressor was developed later and eliminates the need for the timing gears since the oil is supplied in a copious quantity to lubricate, to seal and to cool. The speed of the oil-flooded unit is substantially lower than the dry screw, and the sealing effect of the oil makes it more a positive-displacement compressor and the leakage is minimized. Major cooling takes place in the rotors because the oil is in intimate contact with the compressed gas, and the discharge temperatures are kept low. Actually, only 90 degrees F. temperature rise is experienced on a 100 pound air compressor of this type compared with between 200 and 300 degree F. rise on a reciprocating compressor or a dry screw compressor. An efficient oil separator is then required in the discharge from this machine. They are commercially available and the quality of the air from an oil-flooded screw compressor is comparable to a lubricated reciprocating compressor. Typical quantities of oil remaining downstream of the oil separator are one to two ounces in 40,000 cu. ft. of air. The oil-flooded screw compressor, because of these characteristics, has become even more popular than the dry screw compressor and more widely manufactured and distributed world-wide. This paper will cover the oil-flooded screw compressor primarily, with only occasional specific reference to the dry screw.

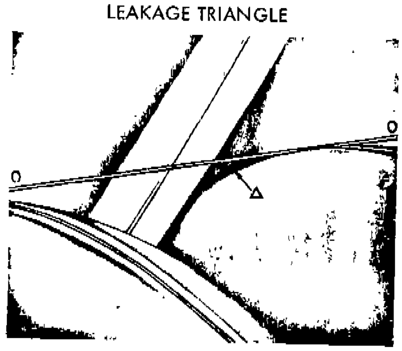
Rotors have become almost standard due to the advantage of four male lobes on one rotor and six female lobes on the other rotor. With this configuration both rotors are the same diameter with good rotor strength. The ratio of length to diameter has been usually 1:1 to 1:1.65, due to manufacturing and tooling requirements, bearing loads and experience factor. The symmetrical profile rotors were first developed; by this we mean across a vertical axis the rotors are symmetrical. However, more recent developments have proven the non-symmetrical profile rotor to be most efficient size for size with an improved performance of 14 per cent.



Symmetrical Rotors   Non-Symmetrical Rotors

This improved performance is due to the reduction in size of the leakage triangle between the male and female rotor as shown in the photo below.

LEAKAGE TRIANGLE



Although the machining is more exacting, the tooling more difficult, the benefits of non-symmetrical profile rotors have been proven, and several manufacturers have gone into production with this configuration. The rotors are machined on the Holroyd with sealing strips to reduce the clearance between the stator and the rotors. The rotors are generally solid with the exception that some of the dry screw rotors have cooling oil forced through the rotors as part of the closed cooling oil circuit. Usually dynamic balancing is required of this type of rotor.

Stators require accurate machining with special attention to parallel axes to very close tolerances. The shape and size of the discharge port is most important and controls the "built-in compression ratio." The inlet port at the opposite end of the machine can be strictly end suction or combination end and top suction. The end suction is more efficient but is expensive to incorporate, requiring a longer stator.

Thermodynamic Characteristics

The screw compressor is generally considered a positive-displacement compressor and many of its characteristics are similar to those of a reciprocating positive-displacement compressor. In the previous paragraph we refer to a "built-in compression ratio." In this matter it differs from the reciprocating compressor. In a reciprocating compressor the compression ratio is strictly the suction pressure to the discharge pressure and is the inverse ratio thereof. The compression ratio is limited only by the strength of the cylinder assembly and by the safety devices used. Because of the porting of the screw compressor, the built-in ratio is controlled by the designer but with the capability of operating off the built-in ratio but then only on a less-efficient basis. When operating above the built-in compression ratio, see the PV diagram, Fig. 1, below showing the shaded area which is the inefficient range. When operating below the built-in compression ratio see Fig. 2. Here again the inefficient range is the shaded area.

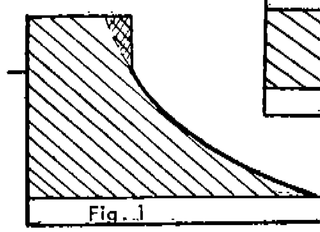


Fig. 1

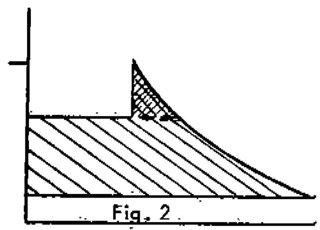


Fig. 2

Such a theoretical pressure volume diagram is not possible in a reciprocating compressor. Figure 3 below is the theoretical reciprocating compressor pressure volume curve. Figure 4 below is a theoretical screw compressor pressure volume curve when operating at the built-in compression ratio. The main difference between these diagrams is the clearance and re-expansion curve at the left side of the reciprocating unit. Since the screw compressor has no clearance, there is no re-expansion involved. The question has been asked therefore, "Is the volumetric efficiency 100% on a screw compressor?". Theoretically, "yes" but practically "no." It is impossible to show on a pressure volume diagram the leakage loss during the compression cycle, but this very definitely affects the volumetric efficiency, and the volumetric efficiency range usually is in the neighborhood of 80-85% due to this loss of efficiency during the compression. The calculation of the displacement of a screw compressor is a mathematical nightmare, so it is not common to discuss volumetric efficiency of a screw compressor, only the delivered capacity in actual cubic feet per minute.

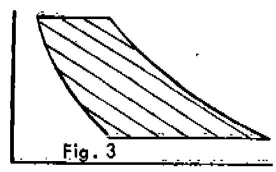


Fig. 3

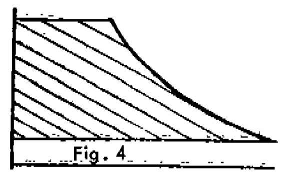


Fig. 4

B. Accessories Required with the Package

1. The separator assembly for removal of oil in the oil-flooded screw compressor package is of major size and cost proportions. In fact, it is usually two to three times as large as the compressor itself and is the oil reservoir as well. The separator element is a renewable insert shaped like a top hat with a multi-layer element consisting of a blanket of fibrous material and parchment separated by a strength member and a second blanket or maze of wire mesh agglomerator on the inside. With the air flow from the outer side to the inner side much of the oil is separated before it goes through to the inner surface; however, some does travel through and is collected on the inside of the separator in the reservoir at the bottom which is returned to the inlet of the compressor through an oil return line. Since this is a direct loss of air when oil is not being returned, the size of this return line is restricted with either an orifice or a capillary tube. A filter and sight glass in this line is helpful to assure successful and continued operation of the return line. The efficiency of the element is dependent upon the cleanliness of the air that it sees. If the air inlet filter to the compressor is properly maintained and clean air is compressed, the separator will operate for one or two years without becoming clogged with dirt and perform efficiently, removing oil to the design criteria of one ounce of oil in 40,000 cubic feet. Besides functioning as an oil reservoir and a container for the separator element, the volume of the separator tank acts as an air reservoir or receiver and makes possible the operation of this compressor successfully without a separate receiver. The benefits of a receiver can be discussed with the compressor manufacturer and supplier, and may be an important separate accessory for the customer's compressed air system depending upon his mode of operation. This subject is not intended to be elaborated on in this paper but is important and should not be overlooked.

2. Coolers - Occupying an important place in the compressed air system are the oil cooler and aftercooler, which is an optional accessory. The oil cooler is extremely important for the successful operation of the screw compressor as the major heat load is rejected from the oil cooler. Three-quarters of the heat of compression is removed in the oil and must be dissipated in the oil cooler. If it is a water-cooled oil cooler, this heat is in turn passed along to the water and must be disposed of either in a closed cooling water circuit having a cooling tower or a radiator, or in an open cooling water system the heat is rejected to the drain. If the oil cooler is air-cooled, a fan draws cool air across the surface and discharges the hot air to the room. A matching aftercooler can be supplied which would be air-cooled if an air-cooled oil cooler is supplied, or water-cooled if a water-cooled oil cooler is supplied. Since it is desirable to have the coldest cooling medium on the aftercooler, the cold water goes first to the aftercooler and then this slightly heated water goes to the oil cooler. Likewise, on an air-cooled unit, the cooler air goes across the aftercooler first before it goes across the oil cooler. The total heat rejection to the water-cooled or air-cooled compressor, including the aftercooler, is 42 BTU/BHP/minute. If no aftercooler is supplied, this heat rejection rate can be reduced by one-quarter. The same total heat load that is experienced in screw compressors is experienced in reciprocating and centrifugal compressors.

3. Oil pumps are of importance and are used on the larger horsepower Twistairs to assure lubrication both during the loaded and unloaded cycle and for cold starts to see that oil is promptly distributed to all bearings and rubbing surfaces. Although some compressors do not have an oil pump, they are usually in the smaller horsepower range for indoor applications where the oil is always easy to flow and where a pressure differential can be easily maintained. A good tight inlet valve will provide adequate vacuum for the suction of oil during the unloaded cycle.

All of these accessories as described above have applied to the oil-flooded screw compressor. The dry screw compressor, of course, needs no oil separator, and the oil cooler is of minimum size because the heat of compression is removed in the intercooler or the aftercooler. Smaller oil pumps are required for the circulation of oil to the bearings. Important in the dry screw compressor are suction and discharge silencers, possibly even interstage silencers to reduce the sound level to an acceptable range. These are usually very expensive and complicated snubbers with internal baffles and tubes.

C. Controls

The controls of the screw compressor are usually mounted on an instrument panel and/or a control center. The instrument panel usually has a start-stop button, a discharge pressure gauge, an hour meter, and various alarm and shutdown switches as desired. The control center usually includes an across-the-line starter, control relays, control power transformer, and terminals for the main electrical leads.

As in other types of compressors, the purchaser can choose between constant-speed control where the compressor runs continuously and loads and unloads without stopping the motor, or a start and stop control where the motor starts and stops in accordance with the demand for air. The latter is satisfactory only on the lower horsepower motors. A combination of constant-speed control and start and stop, called dual control, is also available. Special dual control is a modification that automatically shuts off the compressor if there is no air demand during the unloaded cycle for a given period of time, saving on power.

To adjust the compressor supply to the demand on the larger size screw compressors, a modulating inlet valve is positioned by a discharge pressure signal and only the amount of air is produced that is used. This is called "modulating inlet valve capacity control." A typical diagram is shown below. Note that capacity control is modulated 100% to 40%. Below 40% demand the unit unloads. During the unloaded portion of the curve the horsepower is reduced to less than 25% of full load horsepower.

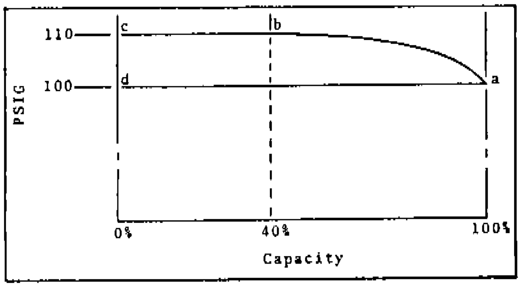
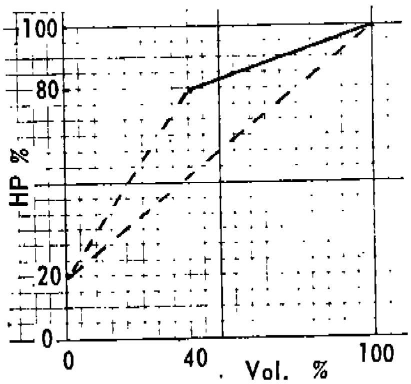


FIGURE 11
Modulation Control



Optional auto-sentry controls are supplied which monitor the oil filter, the oil separator, and the air filter for restrictions, giving an alarm and/or shutdown when they become dirty. The high air temperature shutdown switch is standard and is the main safety device indicating malfunction of the cooler or low oil level and/or mechanical difficulties. A thermister type is the latest fail-safe high-temperature shutdown switch available and is highly recommended.

D. Installation and Maintenance

The salient feature of screw compressor packages is ease of installation. Most manufacturers indicate that they can be installed on any ordinary floor that will support its weight and without any special foundation since there are no unbalanced forces. They can even be put in a room where people are working provided the sound-attenuated enclosures meet the Walsh-Healy Act and the OSHA standards. Many manufacturers list their sound levels at 85 dB A at one meter or less, which is better than any existing code requires. Usually only one voltage is required to be brought in to the package, and in most cases 460 volts is the available 3 phase, 60 cycle current; and magnetic across-the-line starters are usually available inside the package, so only a wall disconnect switch and the 3 phase line need be brought into the compressor. If the unit is water-cooled, the water to and from the compressor are the only two water connections necessary. If the unit is air-cooled, of course a good supply of cooling air is required, but then the dissipation of the air after it has gone through the cooler is a potential problem because of the high quantity of heat added. An air-cooled unit cannot be in a confined space, but the heat must be used or dissipated to the outside at the rate at which it is generated, which is 42 BTU/HP/minute. In a 60 horsepower compressor this is sufficient heat to maintain comfortable temperatures in a 6-room house in the winter. Some companies have used this heat to heat warehouses in the winter and then discharge it through a duct system to the outside in the summer time. Another important consideration is receiver capacity. The reciprocating compressors were always involved with a properly sized receiver to knock out pulsations from an air reservoir and to have a source of control air. On the screw compressor the needs for a receiver are primarily those of a reservoir for surges in use, and a receiver is not absolutely necessary, provided the distribution lines have sufficient volume to take care of temporary surges in demand. Sometimes a receiver is installed near the point of fluctuating demand so as not to disturb the remaining part of the air distribution system. The same general rules apply for distribution of air whether the compressors are reciprocating, screw, or centrifugal. It is desirable to have a loop distribution system when possible, eliminating the possibility of starving a particular tool at the end of a single line.

The maintenance aspect of the screw compressor is a different ball game than the reciprocating compressors that demanded daily filling of oil to the lubricator, continuous checking on packing and adjustment of same, replacement of valves when broken, the changing out of valves for cleaning and the maintenance of filter and replacing of oil. On the screw compressor, because of the few moving parts and low wear rate of these parts, about all that is left to do is to change the filters and the oil regularly. The self-monitoring devices for high air temperature and maintenance of filters and separators make it possible to locate the compressor in an area that does not receive hourly or even daily attention. The maintenance man can be of a non-mechanical type with less technical skill.

E. Economical Considerations

Economical considerations are continually changing, so we will just highlight the areas that should be investigated.

1. The initial investment, and here we find that the screw compressor in comparison with the recip, heavy-duty, water-cooled machine is approximately 30% lower in price per given horsepower size. This, of course, is due to the smaller size of the screw compressor for the given horsepower, its higher RPM, and the fewer parts to manufacture. The price of compressed air has gone down in the past few years due to not only keen competition between manufacturers in the United States but because of the number of compressors being imported and the lower manufacturing cost for some of the rotary compressors. Screw compressors are more expensive to manufacture than sliding vane compressors but generally less expensive than reciprocating and centrifugal compressors in the same horsepower range.

2. The power costs are generally higher on the screw compressor than the reciprocating compressor. This is due

not only to the full load horsepower but also the partial load and no load horsepower. In every case the reciprocating compressor is the most efficient. However, with the invention of the non-symmetrical profile screw, the gap has been narrowed. The actual percentage in power cost difference is hard to pin down because this is depending on whether the unit is operated fully loaded or is only partially loaded. On a fully loaded compressor, comparing recip versus screw compressor, this difference could be as little as 10%.

3. Cooling water costs are no more expensive for the screw compressor or any less expensive than the reciprocating compressor, and we have already talked about air cooling versus water cooling. This is not a consideration for cost comparison as it would be the same whether the compressor is reciprocating, centrifugal, screw, or sliding vane.

CONCLUSION

There are more compressor types and models to choose from today than ever before, and a buyer must be aware of the strength and weaknesses of each type of compressor as well as the reliability of the manufacturer from whom the compressor is purchased. The screw compressor today is available 7-1/2 horsepower through 350 horsepower oil-flooded, and dry screw available from 100 horsepower to 3000 horsepower.

We have considered the important facets of the screw compressor selection and application.

The industrial, heavy-duty, screw compressor took a long time to develop but it is here to stay. Due to its simplicity, ease of maintenance, and overall economy, the screw compressor is making a significant contribution to American production capacity wherever air power is used.