Increasing the Reliability of Screw Compressors in the Gas and Process Industries

a report by
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Screw compressors of the type that is employed in the process and gas industries are large and expensive, while their continuing function is usually essential for continuation of the entire process in which they play a part. The reliability of their operation is thus at least as important as their efficiency. In the past few years, significant advances have been made in the design and manufacture of the main components of machines of this type, such as the rotors and the bearings, as well as lesser components. These have resulted in previously unthinkable improvements to both performance and reliability that have been widely applied to both air and refrigeration compressors. Despite this, process gas compressors have not yet widely benefited from these advances because, for these applications, the numbers produced are far fewer and they have a far longer development cycle than other compressors. Thus, improvements in process gas compressors is now overdue. Moreover, experience already gained in other applications can be incorporated at the design stage, with the minimum of added development time and cost, by simultaneous consideration of all the relevant variables that affect their operation.

Reliability – A Vital Demand in Gas and Process Screw Compressors

Screw compressors have a growing role in the gas and process industry, where their power requirement is high and machine sizes are large. They are simple machines in which the movement of the parts is purely rotational.[1] Therefore, they are typically up to five times lighter than their reciprocating counterparts of the same capacity and have a nearly ten times longer operating life between overhauls. Moreover, provided that the running clearances between the rotors and between the rotors and their housing are small, they can maintain high volumetric and adiabatic efficiencies over a wide range of operating pressures and flows.[2–4]

Specialised machine tools now enable the most complex screw rotor shapes to be manufactured with high tolerances at an affordable cost. Their use in screw compressor manufacture, together with advanced rolling element bearings, has led to substantial improvements in performance and reliability. The development of rotor profiles has recently been enhanced by advances in mathematical modelling and the computer simulation of the thermodynamic and fluid flow processes within the compressor.[5] These analytical methods may be combined to form powerful tools for process analysis and optimisation and are steadily gaining in credibility as a means of improving design procedures. As a result, the design of screw compressors has evolved substantially over the past 10 years and is likely to lead to additional improvements in machine performance in the near future.

Screw compressors in normal use today are based on rotors whose outer diameters range between approximately 75mm and 620mm. These deliver between 0.6m^3/min and 120m^3/min of compressed gas when operating as oil-flooded machines and between 5m^3/min and 600m^3/min in the dry mode. The normal pressure ratios attained in a single stage are 3.5:1 for dry compressors and up to 15:1 for oil-flooded machines. Usual stage pressure differences are up to 15 bars, but maximum values sometimes exceed 40 bars. Typically, the volumetric efficiency of these machines is now over 90%, while specific power inputs that are both size- and performance-dependent have been reduced to values that were regarded as unattainable only a few years ago. The following information is mainly derived from material published by the author, Smith and Kovacevic.[6]

1. *Arbon I M,* The Design and Application of Rotary Twin-shaft Compressors in the Oil and Gas Process Industry, *IMechE, MEP London (1994).*
2. *Sakun I A,* Vintovie kompresorii *(*Screw Compressors*), Mashinostroenie, Leningrad (1960).*
3. *Rinder L,* Schraubenverdichter *(*Screw Compressors*), Springer Verlag, New York (1979).*
4. *O'Neill P A,* Industrial Compressors, Theory and Equipment, *Butterworth-Heinemann, Oxford (1993).*
5. *Xing Z W,* Screw Compressors, *Machine Press, Beijing (2000).*
6. *Stosic N, Smith I K, Kovacevic A,* Screw Compressors: Mathematical Modeling and Performance Calculation, *Springer Verlag, Heidelberg (2005).*

Requirements and Measures for High Reliability

A key requirement for the successful design of all types of compressor is the ability to predict accurately the effects on performance of the change in any design parameter, such as clearance, rotor profile shape, oil or fluid injection position and rate, rotor diameter and proportions and speed. In the case of screw compressors, the main requirement is to improve the rotor profiles so that the internal flow area through the compressor is maximised while the leakage path is minimised. Also, internal friction due to relative motion between the contacting rotor surfaces should be made as small as possible in order to permit higher rotor speeds without excessive mechanical losses. Recent improvements in bearing design make process fluid lubrication possible in some applications. Moreover, seals are more efficient today.

All these developments can be utilised to produce even more efficient, lighter and cheaper screw compressors. Full compressor optimisation, which hitherto has not been used extensively, is especially important and, when properly applied, leads to a unique compressor design for each application. This includes simultaneous consideration of the following factors.

Thermal Expansion of the Rotors and Housing

Modern rotor manufacturing methods, such as grinding with simultaneous measurement, control and correction of the profile, enable the profile tolerance to be maintained within $\pm 5\mu m$. This enables the clearances between the rotors to be kept below $15\mu m$. With such small clearances, rotor contact is very likely and, hence, the profile and its clearance distribution must be generated in such a manner that damage or seizure will be avoided should this occur.

In order to maximise screw compressor delivery rates and efficiencies, interlobe clearances must be made as small as possible without the likelihood of hard rotor contact between the rotors. The traditional practice to avoid rotor contact and seizure was to make clearances larger than required by manufacturing limitations. However, these clearances can be minimised by making their distribution non-uniform around the profile so that if hard rotor contact occurs, it will not be in rotor areas where sliding motion between the rotors is dominant.

The following main effects must be allowed for in the design in order to ensure this.

Although the temperature range over which screw compressors operate is not large, the effects of thermal expansion are highly significant if the small clearances required between the rotors and between the rotors and the housing are to be maintained under working conditions. Thus, the rotor clearances obtained under manufacturing conditions must be estimated while taking account of thermal distortion that will occur when the compressor reaches its operating temperature and pressure.

Clearance Distribution on the Rotor Lobe Flanks

Oil-flooded compressors have direct contact between their rotors. In well-designed rotors, the clearance distribution will be set so that this is first made along their so-called contact bands, which are positioned close to the rotor pitch circles. As the relative motion between the contacting lobes in this region is almost pure rolling, the danger of their seizing, as a result of sliding contact, is thereby minimised.

The traditional approach is to maintain a high so-called positive gate rotor torque, which ensures round flank contact. What is not widely appreciated is that there are significant advantages to be gained by maintaining a negative gate rotor torque to ensure that contact, when it occurs, will be on the flat face. Thus, minimising the clearance on the flat flank will reduce the interlobe leakage more than minimising the round flank clearance. Also, negative gate torque is achieved by making the gate rotor lobes thicker and the main rotor lobes correspondingly thinner. The displacement is thereby increased. Thus, both these effects lead to higher compressor flows and efficiencies.

Displacement of the Bearing Centres

Due to the fact that there must be some clearance in the bearings, the pressure loads will tend to push the rotors apart and displace their centres from their design position with respect to the compressor housing. Thus, if the bearing centres are set to be the same as those of the rotors, the rotors will be eccentric and, as a result, the clearance between the rotors and housing will be smaller at the low-pressure side of the rotors and larger at the high-pressure side. As leakage is caused by the pressure difference, this displacement creates the least favourable rotor position for efficient compressor operation. Also, the resulting rotor displacements from their design positions may cause contact between the rotor tips and the housing unless allowance is made for them during the design. The situation can be remedied by making the bearing centre distance smaller than that of the rotor housing and aligned to maintain a uniform clearance between the rotors and housing. To minimise the rotor interlobe clearance, the bearing centre distance must be even further reduced.

Load Sustainability

A general feature of screw compressors is that the pressure difference through them causes high rotor loads, especially in low-temperature process compressors, where these are large. Therefore, to maintain their rigidity and minimise deflection, the rotors are regularly profiled with a relatively small male rotor addendum in order to increase the female root diameter. This sometimes leads to very shallow and clumsy rotors. An alternative possibility is to increase the female rotor lobe thickness; this greatly increases the rotor moment of inertia and thereby reduces the rotor deflection more effectively. In some compressor designs, multiple cylinder roller bearings or multiple ball bearings are located at the high-pressure end of the rotors to withstand the large radial forces reliably over a long operating life. Frequently, two or more bearings are also employed for axial loads. As only one axial bearing works, the role of the other is usually to clamp rotor and prevent it bouncing in the axial direction.

Compressor Optimisation

Even a simplified analysis of rotor characteristics can show that a number of these lead to conflicting design requirements. This implies that, given the compressor duty, simultaneous optimisation of all the variables involved in the design process must be performed to obtain the best possible performance. The full rotor and compressor geometry can be calculated from the rotor transverse plane co-ordinates and the rotor length and lead. The built-in compressor volume ratio must also be included as an optimisation variable. The values of these parameters should be used as input parameters for the calculation of the screw compressor thermodynamic process, normally by using a mathematical model. Minimisation of the output from the process equations leads to the optimum screw compressor geometry and operating conditions. These can be defined as either the highest flow and compressor volumetric and adiabatic efficiencies or the lowest compressor specific power.

Conclusion

The performance of process gas screw compressors is highly dependent on their rotor profiles and clearance distribution. Moreover, detailed attention is required in the design of other compressor components, such as the housing ports, bearings, seals and the lubrication system in order to obtain the best results. If all these factors are considered simultaneously, the compressor reliability will also be increased. Using up-to-date rotor generation methods, specialised compressor designs are possible that are superior in performance and reliability to most of those in contemporary use and well suited to a growing range of applications and operating conditions in the process and gas industries. ■