

ing the piping while observing the shaft-to-shaft alignment change. An alignment change of no more than 0.002 inch is considered acceptable for most helical-lobe and dynamic compressors.

## Compressors

### Type Comparison

Comparing compressors by type is a somewhat shaky endeavor, because it involves some opinion, some prejudice, and industry-accepted perceptions. Hopefully, the prejudice has been kept under control and the perceptions of industry are based on knowledge, experience, and, at least, some data.

There are two issues to consider in the comparison of the different types of compressors relative to reliability. One is the number of parts required to perform the function. It is generally accepted that reliability is an inverse function of the parts count. This does not necessarily include the number of bolts, for example. The other is the use of wearing parts. On this basis, one would give the centrifugal compressor a higher rating than the reciprocating compressor. To come to a closer comparison, the centrifugal would rate higher in reliability when compared to the helical-lobe compressor, strictly on parts count. To temper this, add that comparisons must include other factors such as the application. The helical-lobe compressor is generally more tolerant of fouling gases than the centrifugal. To take this one step farther, the centrifugal is more tolerant of fouling gases than the axial compressor. The axial again also has a higher parts count, but does have other redeeming factors in its favor such as high capacity for the size and inherent high efficiency. As is typical with all engineering decisions, an overall evaluation is required that applies the appropriate compromises or tradeoffs.

### Reciprocating Compressors

The reciprocating compressor has several strikes against it when it comes to reliability, if the main consideration of reliability is long run times as would normally be expected from the dynamic type machines. It has a lot of parts and the parts are subject to wear. Before one jumps to the conclusion and totally excludes this compressor from consideration because of these factors, the positive aspects of this machine should be

reviewed. For low-volume-high-pressure ratio service and particularly for low molecular weight gases it is difficult to match. When compared to the centrifugal for this service, the centrifugal will have to operate at a high speed and require many impellers. This end of the spectrum is not the best from a reliability point of view for the centrifugal.

If turndown is a consideration, again the reciprocating compressor, with its many unloading options, does meet the challenge. This flexibility is difficult to achieve reliably in the dynamic machine and may require the compressor to operate at an unfavorable point on its characteristic curve.

Several steps can be taken to maximize the run time for the reciprocating compressor. Since wear is a function of rubbing speed, the piston speed can be kept to a minimum. Chapter 3 made recommendations for piston speed. Reliability problems due to valves are reputed to account for 40% of the maintenance cost of the compressor. Valves are the single largest cause for unplanned shutdowns. Basically, valve life can be increased by keeping the speed of the compressor as low as practical. At 360 rpm, the valves are operated six times a second. At 1,200 rpm, the valves operate 20 times a second or 1,728,000 times in a day. It is not difficult to understand why the valves are considered critical. To keep the reliability in mind, valve type, material selection and application considerations such as volume ratio, gas corrosiveness, and gas cleanliness need attention by the experts. One final note is that while lubrication is an asset to the rubbing parts, it is not necessarily good for valve reliability.

While not necessarily improving the reciprocating compressor's individual reliability, using spared units does improve the overall plant reliability. With proper monitoring, the compressors may be removed from service in a timely manner for maintenance. If the program is properly administered, unplanned shutdowns can be avoided and a higher plant reliability achieved.

### Positive Displacement Rotary Compressors

The helical-lobe compressor is the more robust of the rotary compressor types. Its positive reliability factor is the absence of wearing parts if the timing gears are neglected. Timing gears are not used on the flooded type. However, on the negative side, is the parts count. There are two rotors, four bearings, four seals, and, on the nonlubricated machine, there are timing gears. Another negative aspect of the helical-lobe compressor, particularly the nonlubricated version, is the presence of high frequency pulsations. If untreated, these pulsations can contribute significantly to

failures of system components. While this problem may be solved, the solution adds to the system complexity, detracting from the overall reliability. To add a side note, the location of the silencer, used to treat the acoustic pulsations, should be directly attached to the discharge flange if at all possible. There are reported cases of acoustic problems when a spool piece was used between the silencer and the compressor flange. As mentioned before, the nature of the application may alter the overall reliability picture, as the nonlubricated helical-lobe compressor will tolerate fouling gas. It tends to be unique in that arena.

Taking the balance of the lobe-type machines as a group, the biggest single factor leading to poor reliability is excessive rotor deflection. If the rotors are allowed to touch each other, generally a failure occurs. Excessive rotor deflection is caused by a higher differential pressure across the compressor than the design limit. Since most of the rotary compressors, other than the helical lobe are not intended for continuous service, their use in continuous service applications may cause the application to experience reliability problems. Sparing and monitoring for maintenance intervals commensurate with true expected run time will certainly keep the system's reliability up, if the unplanned shutdowns are kept low. Maintenance cost, included in an evaluation of life cycle cost, may well direct usage to a more suitable compressor selection.

## Centrifugal Compressors

Centrifugal compressors can be very reliable, but having said that, they can also have a miserable reliability record. It is tempting to relate some of the horror stories encountered on poorly designed, poorly applied centrifugal compressors. The reader, wanting to learn from this, is directed to the literature, as there have been many volumes written on this subject. At this writing, it can be said that improvements in reliability for this compressor over the past 30 or so years have been significant.

Probably the single largest contributor to problems in the centrifugal compressor is related to rotor dynamics. Long slender rotors are the Achilles heel of this machine. It is in this design that the term robust has a great deal of meaning. Rotors are subject to critical speeds that must be encountered during startup. The longer the rotor and the higher the speed, the more the number of critical speeds that must be dealt with. To this can be added the sensitivity to unbalance. In field operation and as time passes, the compressors do degrade, which usually manifests itself in

ever-increasing levels of unbalance. All this boils down to the simple fact, the more sensitive the rotor, the shorter the runtime.

Another area of concern is rotor stability. Two factors enter into the stability considerations: flexibility, just discussed, and damping. Most of the rotor damping is generated by the bearings. The design must consist of bearings with adequate damping capability and rotor motion in the bearings to generate the damping. One of the significant destabilizing forces is aerodynamic cross coupling from the impellers. This is of greatest concern with high density applications. Squeeze film dampers may be added to the bearing to generate more damping but detract because this adds a degree of complexity. Designs are very empirical and are difficult to evaluate: when they are good they are good and when they are bad they are terrible.

Individual designs must cope with the tradeoffs or compromises necessary for good reliability and yet maintain good efficiency. Unfortunately, these forces are somewhat in the opposite direction from each other. One of the first issues is speed; high speed is generally good for efficiency but can cause problems with reliability. High speed raises stresses, which must be limited for reliability. High surface speed may cause bearing and seal problems if allowed to encroach on the limits of experience. One solution is to add more impellers, but that may lengthen the bearing span to a degree where the rotor dynamics may be compromised. Another consideration is the use of multiple cases connected in series and tandem. While this is sometimes the safe option, it does increase the parts count—more bearings, more seals, and more couplings, as well as increasing the cost.

While the previous statements tend to paint a rather bleak picture, the purpose of the material is not to discourage but to help the reader understand the aspects of the reliability decisions. Also as mentioned before, the centrifugal has progressed considerably in the last 30 years. More progress is yet in the works with new analytical and diagnostic tools. This, coupled with improvements in machine health monitoring, make the centrifugal compressor outlook much brighter. It would be safe to say that it is the compressor of choice whenever the application allows.

## Axial Compressors

Axial compressors offer a high volume capability in a relatively compact case. As can be said for any of the dynamic compressors, when properly applied, it can be a very reliable compressor. The compressor