

## Gearbox Guidance for Pipeline Applications



Voith Turbo BHS Getriebe, 06/2012, by Tome Stanic

## Gearbox Guidance for Pipeline Applications

**Direct-driven pipeline compressors and pumps are fine in the right circumstances – but for many applications a gearbox is still the best option. Gear units are key components, yet don't always get the attention they deserve. Here is what to look for when choosing a gearbox for maximum reliability in specific applications.**

Pipeline compressor and pumping stations are diverse in their drive train arrangements. The choice of compressor or pump, and the corresponding prime mover, are influenced by the balance of capital costs, efficiency over a range of operating conditions, maintenance costs and reliability. These in turn depend on the fluid transported, the size of the pipeline, the location and the nature of the terrain.

In much of Europe and the USA, pump or compressor sta-

tions are accessible and ambient temperatures are not extreme. In remoter areas, however, access for maintenance can be much harder. Temperatures range from desert highs of 60 °C to Arctic lows of –45 °C, and humidity is a problem in tropical areas.

The choice of prime movers is between gas engines, gas turbines, and electric motors, both high-speed and low-speed. Which is best depends on the availability of fuel and electric power, energy costs, efficiency and reliability.

The constraints on the choice of driver and driven equipment mean that in many cases direct drive is impossible and so a gearbox is needed. The gearbox is a critical component, yet it does not always receive the attention it deserves. Understanding different gearbox designs and refinements is therefore important in maximising reliability and minimising maintenance costs for the whole drive train.

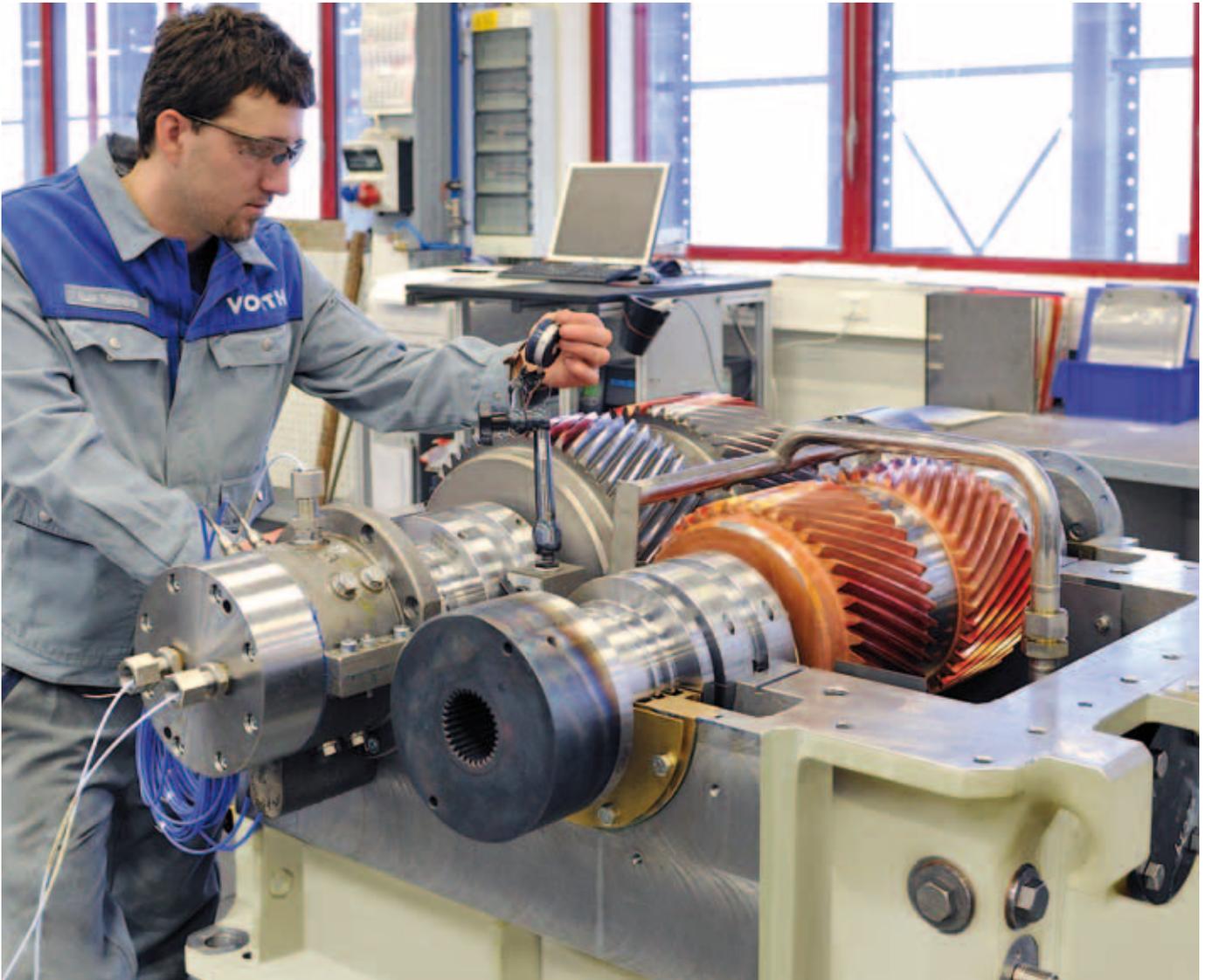


Figure 1:  
Gear units for compressor and pump drives must be extremely reliable while enduring high stresses at high speeds, often under demanding environmental conditions. Their selection needs as much care as that of the prime mover and the driven equipment.

### Gas Pipelines: gearboxes are still the usual choice

Modern natural gas pipelines almost always have high-speed centrifugal compressors, though many older reciprocating compressors are still in use. Regardless of whether the driver is an electric motor or a gas turbine, a centrifugal compressor frequently requires a gearbox.

For electric drive, the traditional arrangement is a low-speed motor with a step-up gearbox. At power ratings up to 15 MW most applications use 4-pole induction motors, which run at 1,500 rpm (50 Hz) or 1,800 rpm (60 Hz). For larger motors, variable-speed drives are often added, or synchronous motors substituted. At very high powers (60 MW and above), 2-pole (3,000/3,600 rpm) induction motors come into their own.

Direct-drive high-speed motors with magnetic bearings and electronic variable-frequency drives (VFDs) have recently become available. The first applications of this new technology have generally performed well in the benign environment of central Europe, but reliability under harsh conditions has not always been good [1]. As a result, Voith Turbo BHS has noticed a trend back towards proven low-speed motors with gearboxes.

The Voith group also produces variable-speed drives which combine hydrodynamic components with planetary gears. Vorecon variable-speed drives were introduced to the oil and gas industry in 1995 and are now used in several hundred applications as a reliable and economic alternative to VFDs.

Where reliable grid power is not available, gas turbines are the usual alternative. Aeroderivative turbines typically use direct drive. Industrial gas turbines run most efficiently at lower speeds, so they generally require step-up gearboxes.

Electric motors and gas turbines tend to place different demands on their respective gearboxes. Low-ratio gas turbine gearboxes are frequently characterised by high power density, which imposes great stresses on the gear teeth. Gearboxes for low-speed motors have large speed ratios, which can create challenges in rotordynamics. The following sections explain these differing requirements in more detail.

### Gas turbines: high loads

Industrial gas turbines with power ratings up to 50 MW and running at 5,000–10,000 rpm need step-up gearboxes to match them to centrifugal compressors speeds of 10,000–20,000 rpm.

Because power is proportional to speed, these relatively high input speeds create high power densities within the gearbox. The linear velocity of the gear teeth (“pitchline velocity”, PLV) can be up to 185 m/s in normal operation, and even higher under gas turbine fault conditions.

Such high PLVs place great stresses on the gear wheels and especially the teeth. For the larger of the two gears (the bull gear), case-hardening and one-piece forging are recommended to improve performance and reliability.

In most parallel-shaft gear units, the smaller of the two gears (the pinion) is case-hardened but the bull gear is not. Gear units in which both bull gear and pinion are hardened can

transmit more power, or for the same power rating they can be made smaller, with higher efficiencies and lower oil volumes. Demanding end-users such as the major oil companies recognise this as the state of the art in parallel-shaft gear units.

For PLVs above 150 m/s Voith Turbo BHS recommends that the bull gear should also be forged in one piece with its shaft. This eliminates the stresses associated with shrink-fitting the gear onto the shaft, and any risk of subsequent detachment. High power implies relatively wide teeth and high squeezing forces between the meshing teeth. The resulting high temperatures can degrade the lubricant and increase the risk of scuffing. For safety, the lubricant should be a mineral oil with extreme pressure (EP) additives rated to a Failure Load Stage of 7 or higher in the standard FZG test.

High PLVs can create unwanted turbulence within the gear casing. This can interrupt oil circulation, increasing the probability of oil foaming and overheating. Ways to reduce this include choosing an oil path which follows the direction of rotation of the bull gear, and special baffles to guide the oil.

Small deflections caused by bending forces and moments, centrifugal forces and thermal deflection can interfere with the smooth meshing of helical gears cut with a straight lead profile. Unlike some other gear manufacturers, Voith Turbo BHS uses an advanced lead profile to ensure smooth meshing and reduce peak loads by distributing the load along the entire tooth flank.

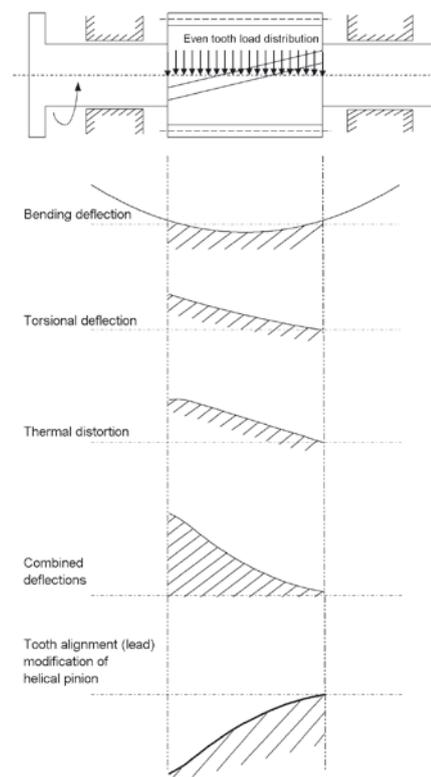


Figure 2: The advanced lead profile of this BHS helical gear ensures uniform load distribution by compensating for various deflecting forces. This is especially important at the high power densities characteristic of gearboxes driven by gas turbines.

Apart from the actual gears, bearings too require careful attention. The bearings on the high-speed shaft typically have to handle both high journal velocities (70–100 m/s) and loads up to the 3.45 MPa maximum allowed by API 613. This limits the choice to either tilting pad bearings or high-capacity fixed bearings with an offset or elliptical profile.

For parallel-shaft gearboxes Voith Turbo BHS manufactures its own fixed profile bearings, purpose-designed to ensure proper stability and rotor damping under the challenging conditions imposed by high-speed gearboxes. On their own test bed these have proved to out-perform other bearing types such as tilting pads in terms of temperature, oil consumption and efficiency.

### **New design doubles previous limits**

Taken together, the challenges facing conventional parallel-shaft gearboxes for compressors driven by gas turbines re-

strict the power transmitted to 25–35 MW, depending on the speeds required.

To overcome this limit, Voith Turbo BHS offers an alternative design known as the power distribution gearbox.

Here the power is transmitted through three planet gears, as in an epicyclic gear, instead of the single pinion used in a parallel-shaft gearbox. This division of power means that the individual gears can be smaller in diameter, so PLVs, centrifugal forces and stresses are all reduced by an average of 20–40 %. Power distribution gearboxes were developed in the 1960s and by now are thoroughly proven; the design meets the intention of API 613 for safety and reliability.

A power distribution gearbox driving a compressor at 12,500 rpm from a gas turbine at 5,000 rpm can transmit up to 65 MW, compared to the 25 MW limit for a parallel-shaft gearbox at the same speeds. Power distribution gearboxes in other applications can handle up to 170 MW.

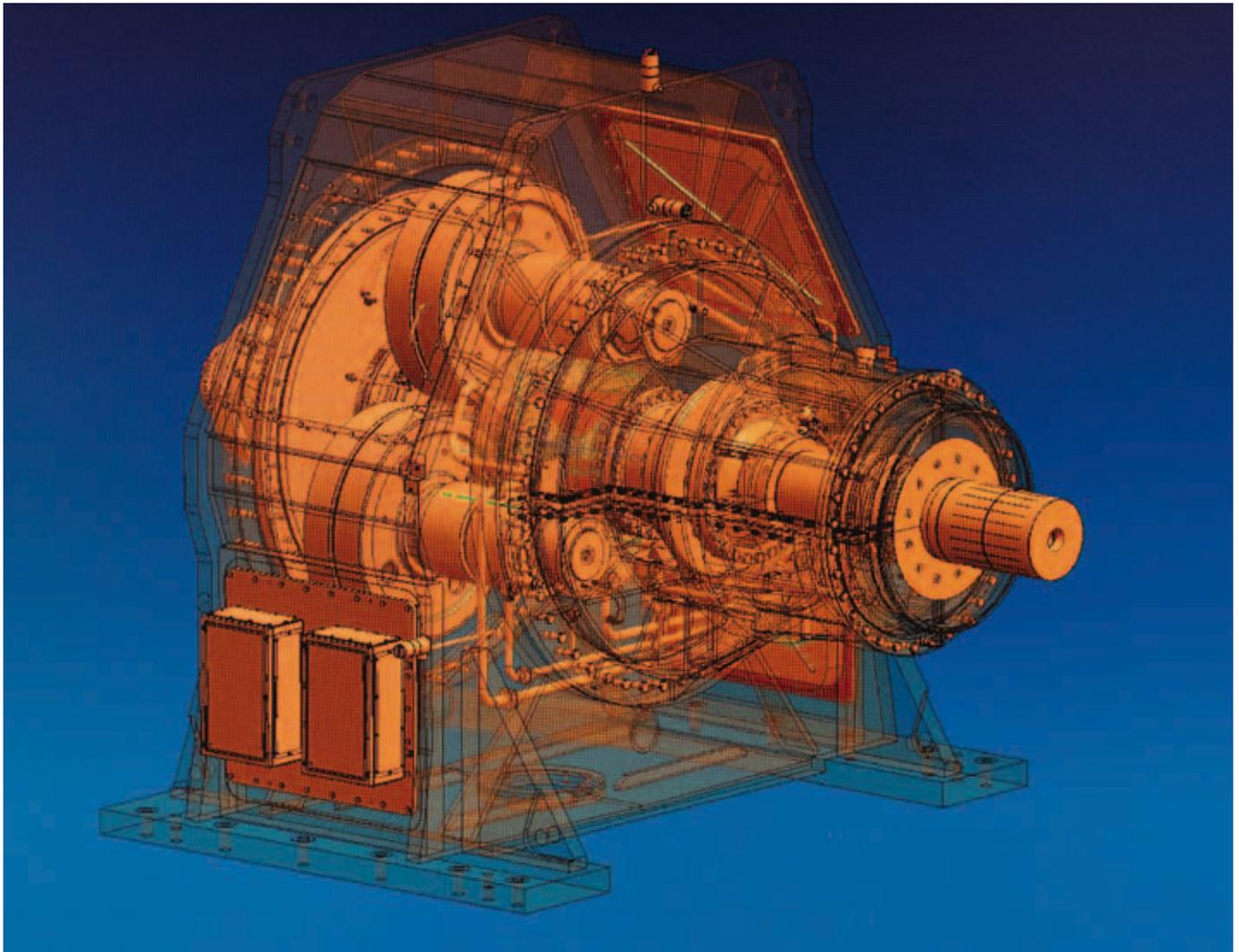


Figure 3:

By splitting the load over three planetary gears instead of a single pinion, the BHS Power Distribution Gear can transmit more than twice the power possible with a parallel-shaft gearbox.

### Electric motors: high ratios

Where a reliable power supply is available, electric motors are attractive for power ratings up to 15 MW or more, with power densities approaching those of gas turbines.

Gearboxes for centrifugal compressors driven by low-speed electric motors face similar challenges to gas turbine gearboxes in terms of bearing speeds and loads. In other respects, however, they are very different.

A 2-pole induction motor runs at around 3,000 rpm (50 Hz) or 3,600 rpm (60 Hz). To drive a typical compressor at 18,000 rpm therefore requires a gearbox ratio of 5 or 6. To match compressors to the commoner 4-pole motors (1,500/1,800 rpm), single-stage gear ratios of up to 10 are not unknown. Such high ratios, combined with the high powers and high speeds required, are very challenging.

A high gear ratio means a large difference in diameter between the (low-speed) bull gear and the (high-speed) pinion. The relatively small diameter of the pinion imposes high bending forces and limits the diameter of the bearing that can be used.

To provide acceptable rotordynamics, a very light coupling must be used on the high-speed shaft. Neither tooth couplings nor most types of lamella couplings are suitable, due to their relatively high mass and resulting overhung moment. Voith Turbo BHS relies on its own TwinTors® double diaphragm couplings to keep the overhung moment low. The ability to design and manufacture both gearbox and couplings as a complete system allows them to optimise rotordynamics and torsional stiffness, and the TwinTors® couplings are frictionless and low-maintenance.

On the large-diameter bull gear the power density may be lower than in the case of gearboxes for gas turbines, but PLVs can still be high enough to warrant an integrally forged bull gear. The large bull gear diameter can also create excessive turbulence, which needs to be controlled by oil baffles and other modifications inside the casing.

For speed ratios above 6, Voith Turbo BHS offers an alternative design offering high efficiency in less space and with lower weight compared to a standard parallel-shaft gear unit. The

advanced epicyclic design is based on more than 80 years' experience with this type of gear unit and more than 8,000 units operating reliably and safely worldwide. These include motor-driven compressors in German refineries with more than 250,000 running hours each. This compact and efficient gear design meets the intention of API 613 in terms of safety and reliability.

### Liquids transport: temperature is critical

Compared to centrifugal compressors for transporting gas, the pumps used to move oil, water and other liquids along pipelines have lower operating speeds – typically not above 3,500 rpm – and so are less likely to require complex gearing. Prime movers for pumps include electric motors, gas turbines and diesel engines, of which the first two are the most popular for long-distance pipelines. Fuels tend to be liquid, supplied independently from the fluid being pumped.

Compared to those for centrifugal compressors, pump gearboxes generally have less-demanding power densities and speed ratios, and so are less likely to operate close to the limits of current technology. By following the service factors recommended by API 613, operators can achieve high enough safety margins for reliable long-term operation.

However, there are other factors to consider apart from the actual gear design – notably ambient temperature. Pipelines in the Middle East can see daytime temperatures of 65 °C, falling quickly at night to near freezing. When the gearbox oil experiences inlet temperatures approaching 60 °C, its lubricating properties decrease and the risk of scuffing on the gear teeth increases.

Voith Turbo BHS UltraCool Bearings (Figure 4) run around 10 °C cooler than conventional bearings, thanks to features such as special cooling channels within the bearing chassis. The lower temperatures increase bearing life and the oil lasts longer too. For the gears, highly polished surfaces reduce the risk of scuffing. These can be achieved through state of the art machining and grinding, and optionally by copper or silver-plating the surface of the pinion.

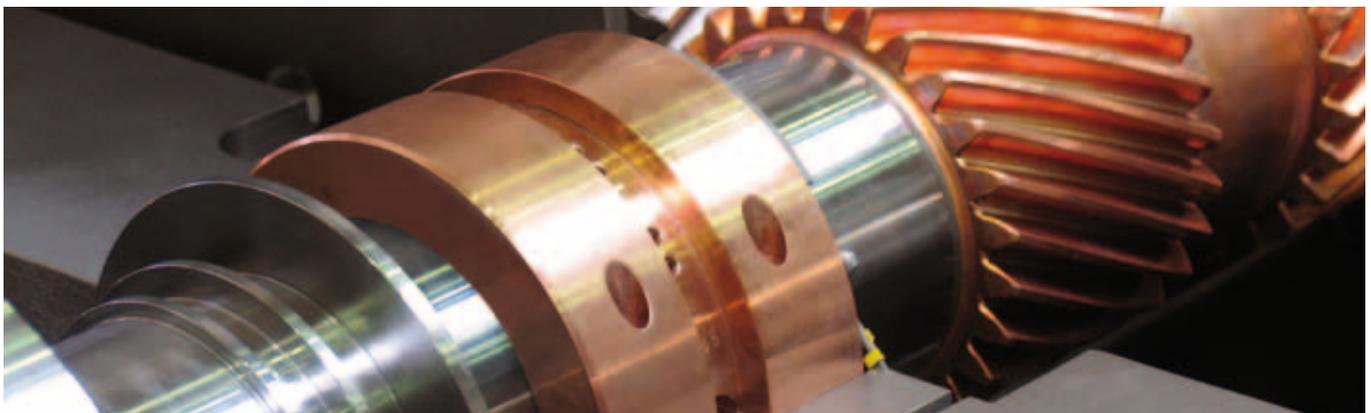


Figure 4:

BHS UltraCool Bearings, shown here supporting a double helical gear, run around 10 °C cooler than conventional bearings. This prolongs the life of the bearings and lubricant, and is especially valuable in very high ambient temperatures.

Example 1

**Beating the heat in Algeria - with special bearings**

In the Algerian desert, Voith Turbo BHS UltraCool journal bearings have helped to ensure gearbox reliability for equipment manufacturer GE Nuovo Pignone and operator Sonatrach since 2006.

The application is a parallel-shaft gear unit transmitting 32.7 MW from a gas turbine running at 4,670 rpm to a residue gas compressor at 9,100 rpm.

The specified maximum bearing temperature is 90 °C at 100 % load, an oil inlet temperature of 49.5 °C and oil inlet pressure of 1.7 bar. The bearing load is 3.3 MPa and the PLV is 90 m/s.

In operation, the actual bearing temperature does not exceed 78 °C, and the oil temperature rise is limited to 23 °C compared to its specified maximum of 35 °C.

Voith Turbo BHS confirmed the performance of the new bearings at its dedicated bearing test stand in Sonthofen, Germany. This allows testing at full load and under realistic operating conditions, as required by the customer.

UltraCool Bearings have since been installed in 20 separate oil and gas industry projects, where they have performed exactly as expected.

At the other end of the thermometer, Arctic temperatures down to -45 °C make materials of construction very brittle. Gearbox materials must be carefully chosen to reduce the risk of breakage during transport and installation. Lubricants must be suitable for these extremely low temperatures, and oil pre-heaters are needed to allow safe starting from cold.

Example 2

**Bitter cold in the Gobi Desert - special housing steel**

Winter temperatures in the Gobi Desert of China and Mongolia can fall below -40 °C, causing ordinary steels to become dangerously brittle.

In 2006, operator PetroChina specified -30 °C as the low-temperature limit for gearboxes in five compressor stations serving a pipeline which crosses the Gobi. Each gearbox needed to transmit 20 MW from an electric motor running at 1,800 rpm a centrifugal compressor running at 8,594 rpm. Equipment supplier MAN Diesel & Turbo commissioned Voith Turbo BHS to supply gearboxes with housings made from special low-temperature steel to reduce the risk of damage.



Figure 5: Voith Turbo BHS parallel-shaft gear unit in compressor station at YangQu for the Shaanxi to Beijing pipeline of PetroChina with 20,000 kW power, input speed 1,800 rpm, output speed 8,594 rpm.

## Summary

Table 1 summarises the main features and benefits to check when selecting a gearbox for a pipeline application.

Feature	Advantage	Benefit
Case-hardened teeth	Less risk of damage from centrifugal forces	Higher reliability
Bull gear forged in one piece	Eliminates risk of detachment	Higher reliability
Oil failure load stage 7	Reduces risk of scuffing	Higher reliability
Advanced lead tooth flank profile	Uniform loads on gear teeth	Higher reliability
Oil path follows direction of rotation	No interruption of oil circulation	Higher reliability
Appropriate bearings	Better economics Improved rotordynamics	Higher return on investment Higher reliability
Lightweight coupling on high-speed side	Improved rotordynamics	Higher safety
Option of alternatives to parallel-shaft gears	Keep up with market demands	Higher safety

Table 1: Features and benefits to look out for when selecting a gearbox.

## Conclusion

Although many pipeline power trains now use direct drive, in some cases the need to get optimum efficiency and performance from specific drive train components demands the use of a speed-increasing gearbox.

Depending on the configuration and the choice of prime mover (gas turbine or electric motor) and working machine (pump or compressor), the gearbox faces various challenges specific to the application. Careful consideration of all the factors rele-

vant to the gear design, and proper specification, are crucial to avoid loss of reliability during operation.

Beyond the application-specific design considerations, gearbox manufacturers also need to bear in mind environmental factors, especially if the gearbox will operate at Arctic or desert temperatures.

A gearbox that is optimised for the demands placed on it benefits the entire train in terms of reliability, efficiency, performance and operating costs.

## References

- [1] <http://www.gaselectricpartnership.com/GGEP%20Electric%20Motor%20Guidelined.pdf>  
Gas Electric Partnership Conference, February 2012

## Contact

Voith Turbo BHS Getriebe GmbH  
Tome Stanic  
Head of Business Development  
Phone +49 8321 802 535  
Fax +49 8321 802 685  
Tome.Stanic@voith.com

[www.bhs-getriebe.de](http://www.bhs-getriebe.de)

Voith Turbo BHS Getriebe GmbH  
Hans-Boeckler-Str. 7  
87527 Sonthofen, Germany  
Phone +49 8321 802 0  
Fax +49 8321 802 689  
info.bhs@voith.com

[www.bhs-getriebe.de](http://www.bhs-getriebe.de)

**VOITH**  
Engineered Reliability