As oil exploration moves further offshore into deeper water, the oil reservoir pressures increase far beyond those experienced in the past. Therefore, injection pumps used to support the oil reservoir pressure need injection pressures far above the technology of existing centrifugal pump designs. Sulzer Pumps has trodden new paths – and developed the world’s highest-pressure centrifugal injection pump.

The exploration of deep-water oil fields requires injection pumps with extremely high pumping heads (Fig. 1). Oil companies have selected several pump companies to develop designs to meet their tough demands. This gives them the opportunity to participate and review the designs and manufacturing processes thoroughly, to address interfaces to the other equipment and assess risks in an early phase. Robust, reliable pump designs as well as safety of the operating personnel and production facility are of high priority.

Based on Experienced Designs
The very high pumping head – up to 5600 m or 580 bar – demonstrates the biggest challenge. In order to minimize risk, the pump selection criteria such as hydraulics, speed, head per stage, number of stages, and design pres-
The range chart of type HPcp injection pumps could be expanded with the development of ultra-high-pressure injection pumps covering a pumping head up to 6000 m.

Two designs of ultra-high-pressure injection pumps are available. With the impellers arranged in-line (top), the drive power may reach up to 34 MW. With the impellers arranged back-to-back (bottom), a pumping head up to 6000 m is possible.
Barrel casing with bolts. When using high pressures, special attention has to be paid to the sealing of the delivery cover.

The deflections of the bolted delivery cover connection at operating condition have been analyzed utilizing 3D modeling techniques and analyzing tools. Figure 4 shows the typical deformation at operating condition presented in an exaggerated view. With this analysis it can be proven that a positive surface pressure at the inside of the bolting near the o-ring groove can be maintained, thus eliminating any possible o-ring extrusion at all operating conditions.

For safety reasons the suction casing has to be sealed to the atmosphere for the full discharge pressure if there is no pressure relief system installed in the suction pipe. Only a radially arranged sealing system is feasible by design. With rising pressure the radial extrusion gap increases. A sealing system for this purpose consists of a tough, resilient, T-shaped ring with a pressure-actuated anti-extrusion ring used in the aeronautical industry. For the first ultra-high-pressure pump a test rig which reproduced this radial gap under this high pressure was built for testing the sealing system prior to pump manufacture. The tests were successful and confirmed that the suction end sealing system was fit for purpose.

Protection Against Sand Wear
Injection pumps must be capable of handling sand, especially if produced water is pumped. The components forming the close running clearances have to be protected by using newly developed HVOF coatings or wear parts with solid tungsten carbide inserts (see STR 1/2001, p. 22).

Highest Pressure in the World
For the BP Thunder Horse project in the Gulf of Mexico, Sulzer Pumps has participated in a develop-
opment competition and, in 2001, was awarded the manufacturing and testing of the prototype injection pump with the highest pressure in the world. The pump had to generate a head of over 5600 m, turned at 6000 rpm and was driven through a gearbox with a 10-MW variable-frequency drive motor. The selected pump was of the back-to-back design and had 12 stages. The material of construction was super duplex stainless steel with high strength and corrosion resistance.

The pump was vital to the customers’ project success. Since a pump with such high pressure had never been built before, a prototype pump was manufactured and extensively tested. The hydrostatic pressure test had to be conducted under severe safety precautions. The pump test assembly was set up in a pit not accessible to the test personnel. The pressure was increased incrementally up to 957 bar (65% higher than the required operation pressure) and successfully held at that pressure for 30 min.

The predicted hydraulic performance was confirmed with the performance test conducted at full speed at the Sulzer Pumps test facility in Leeds (UK). The customer’s requirements including the standards of API 610, 8th edition, could be met.

Rotordynamic tests were carried out running the pump at full speed and full load (Fig. 5) with two times new running clearances simulating end-of-life condition. The stiffness gained with close running clearances is reduced with large clearances, thus vibration is expected to be higher. Hardly any change of the low vibration level was detected between the tests with new and worn running clearances. Vibration levels were all within the limits set out in API 610 across the full operating range. In addition, unbalance was added to the coupling to check the rotor sensitivity. The measured vibration amplitude was below the predicted value.

All test results fulfilled the customer’s requirements and demonstrated that the pump is robust even with end-of-life running clearances. The customer then released an order for three additional complete pump units.

This new and innovative development of ultra-high-pressure injection pumps allowed Sulzer Pumps to extend its range of pumps in order to meet even more challenging demands in the future.

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5 A Thunder Horse injection pump unit mounted on a massive skid – destined for BP’s deep-water field development in the Gulf of Mexico – is ready for a full-speed, full-load string test with all its auxiliary equipment and instrumentation in the Sulzer Pumps manufacturing facility in Leeds (UK).