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Operating a Lineshaft Production Pump in a Small Pump Chamber Under Highly Aggressive Geothermal Fluid Conditions: Results from the Soultz EGS Site

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ABSTRACT

The Soultz geothermal power plant is the first plant to be built in France, aimed at exploiting EGS (Enhanced Geothermal System) technology. It has undergone trial operation involving one production well and several reinjection wells drilled into deep fractured granite (5 km). The geothermal fluid, a very saline brine with a high gas-liquid-ratio is lifted at 160°C and produced to surface by means of a Line Shaft Pump (LSP). This LSP is installed in the production well GPK-2, in a $9^{5/8}$ inch pump chamber. Since 2008, several aspects of the LSP have been tested and improved in order to deal with all the technical challenges at the Soultz site.

The first LSP was supplied by an Icelandic company, which had been very successful in Icelandic applications. It was installed at Soultz in May 2008 and since its start-up in June 2008, the whole LSP assembly has been removed and reinstalled seven times due to various operational and technical failures. Most of the failures were related to abrasion, corrosion and scaling damage of the combined production/driveshaft/pump assembly due to the very aggressive geothermal conditions in Soultz. Unfortunately, the supplier of the first generation of pump assembly could not offer an ideal technical solution for the Soultz well conditions. Thus, a development was initiated and is still being carried out to build new pump components adapted to the very aggressive geothermal brine. The first phase of the project involved the design of a new hydraulic pump assembly with the aid of a German supplier, based on their experience and existing products. This was built and tested under laboratory conditions in December 2012, installed in Soultz in January 2013 and was operated successfully at 30 Hz for nearly six months. In a second project phase a complete new pump has been developed with local producers, in order to reduce casting and maintenance costs. At this stage, attention has also been given to analysis and control of natural frequencies of vibration in the Soultz LSP.

1. INTRODUCTION

The Soultz geothermal power plant is located within the Upper Rhine Valley in Northern Alsace about 50 km NNE of Strasbourg. This is the first EGS demonstration site producing electricity in France (Genter et al., 2013). Soultz geothermal fluid is Na-Cl-Ca dominated brine with a salinity of 100 g/L and a gas-liquid-ratio of 1:1 (mainly 85% CO_2, 10% N_2, and 2.5% CH_4) (Sanjuan et al., 2010). The production well GPK-2 is designed with a $9^{5/8}$ inch pump chamber of length 510 m (Baumgaertner et al., 2000). This production well is slightly deviated from the surface to 150 m deep, but then starts to be significantly deviated at 300 m deep.

The first LSP tested in Soultz was supplied in 2008 by an Icelandic company, which offered the possibility of driving the pump via a lineshaft with water-lubricated Teflon bearings (Genter et al., 2009). This company had supplied more than 100 pumps operating in Iceland and 15 in other countries, pumping medium temperature geothermal brines (<120°C max) at shallow depth (100 m to 200 m). Operating the pump in Soultz conditions was a challenge. However, the Soultz pump chamber casing is of only $9^{5/8}$ inch diameter and this company was also the only one offering an LSP adapted to this limited diameter. A standard 2900 rpm US pump assembly was proposed, with 17 cast iron pump stages and extra impeller axial clearance of 18 mm. Standard also were the 3 040 mm long carbon steel shaft elements, each with two 316 stainless steel sleeves to act as inner bearing surfaces and two 1 520 mm long carbon steel enclosing tubes per element, coupled together with Teflon outer bearings positioned to complete the shaft bearing system. Figure 1 presents a schematic drawing of the whole production column and a photographic view of the standard Icelandic water-lubricated LSP lineshaft/production tube column assembly construction. Shaft elements are screwed together to make up the required total length, as are also the enclosing tube elements.

The driveshaft is suspended beneath the high thrust electric drive motor and runs in steel/Teflon bearings positioned respectively on its outer surface and in the same axial position within its enclosing tube, which in its turn slides into the inner ring of the centralisers. These are clamped between the elements of the production pipe. Thus, via this two-stage enclosure, the rotating driveshaft gains a substantial increase in bending stiffness.

Upon attachment to the driving flange of the motor and adjustment of the shaft length to an optimum to allow for the relative positions of impellers and stator bowls as their state varies between off-load and operation-induced thermal and mechanical loading, the water lubrication system is connected to the upper end of the shaft's enclosing tube, tensions of enclosing tubes is set and the system may be started up.

2. BRIEF HISTORY OF THE SOULTZ LSP EXPERIENCES

The first LSP was installed in Soultz in May 2008 and operating from June 2008. First failure in August 2008 was caused by carbonate scaling inside the enclosing tube due to the use of drinking water for lineshaft bearing lubrication (Genter et al., 2010). Carbonate scaling inside the enclosing tube heated the shaft by friction, leading to a breakdown of the top shaft. Domestic drinking water was first replaced by softened water, but this measure did not eliminate completely the scaling inside enclosing tube. For this reason, since 2009, Soultz LSP has been lubricated with water purified by reverse osmosis and with sulphite treatment against oxygen. The modification has increased operating cost compared with operational experience in Iceland, where LSP's are lubricated directly with the geothermal brine. Since that change in 2009, no more carbonate scaling has been observed.

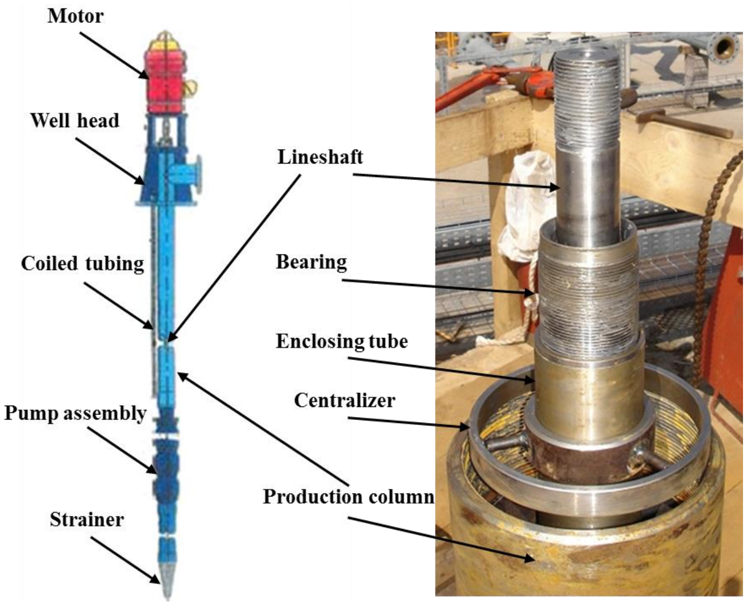

Figure 1: Draft of the standard Icelandic water lubricated LSP (left) and view of the standard production column assembly(right)

Figure 2: View of the carbonate scaling observed in August 2008 with drinking water lubrication (on the left), lineshaft break(in the middle) and scaling observed in June 2009 with softened water lubrication (on the right)

Unfortunately, Soultz operation conditions are more aggressive than Icelandic conditions: high content of chlorine in the brine, high gas-liquid-ratio, high dissolved carbon dioxide in the brine, and carry-over of cuttings from the reservoir and deviated well. The following failures are all mostly related to damages to pump assembly components due to abrasion and corrosion. Each time the pump assembly was removed from the production well, considerable signs of wear and damage could be observed on both rotary and stationary parts. The impellers and bowls were also highly corroded. Investigation with environmental scanning electron microscopy revealed an embrittlement of iron oxide with a soft layer of iron arsenide (geothermal brine contains 4-6 mg/L of As) (Scheiber et al., 2015). Some impellers and stator bowls were damaged seriously by being effectively sandblasted. Sand, scaling or debris trapped by centrifugal force had abraded impellers' necks or the stator bowls. These kinds of abrasion-corrosion damages reduced step-by-step the hydraulic performances of the pump.

In November 2011, the pump was stopped and removed because of a leakage inside the enclosing tube (Genter et al., 2012). The thread of one of the driveshaft's enclosing tube elements and various centralisers were seriously damaged. Investigations with CETIM CERMAT in Mulhouse, France, concluded that the origin of these damages was stress corrosion due to high vibration of the pump. The vibrations were the result of insufficient tensioning of the enclosing tube. This bad experience showed up the importance of the LSP adjustments before start-up. In Figure 4, a view is presented of the damaged enclosing tube and of one damaged centraliser.

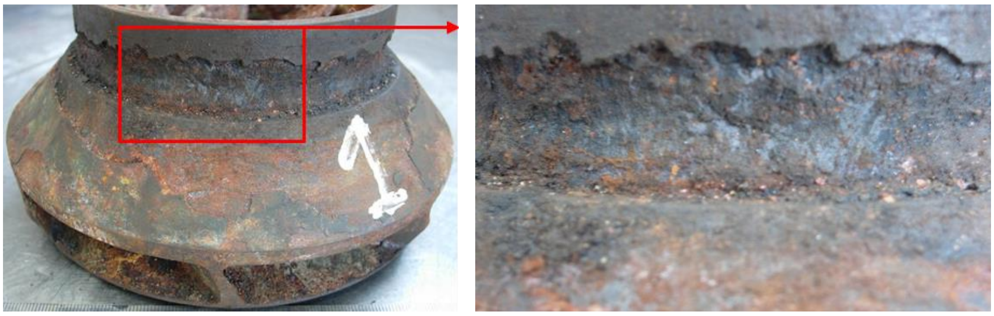

Figure 3: Views of wear caused by "sand-cutting" of impeller No.1 of the pump removed in May 2012

Figure 4: View of the leaking driveshaft-enclosing tube and of one centraliser damaged by stress corrosion and removed in November 2011

Between 2009 and 2012, several attempts were made to improve the lineshaft bearing firstly with new Teflon insert fastening with welded rings instead of pins, and then by replacing Teflon with bronze. Teflon fastening with welded rings was not really successful because the axial thermal expansion of the Teflon, which was not taken into account leading to radial expansion and high shaft friction. Bronze material, commonly used with oil lubrication, was not a success with water lubrication: after 5 days of operating, the pump was stopped due to high vibration level. After pump withdrawal, it could be observed that all the bronze bearings were ovalised and some of them had gained 2 mm in their diameter. In Figure 5 the different lineshaft bearings tested during this period are shown.

Figure 5: View of the different lineshaft bearings tested in Soultz: standard Icelandic (on the left), with welded rings and carbon-graphite Teflon insert (middle) and bronze bearing insert (on the right)

3. PUMP DEVELOPMENTS IN SOULTZ

Production pumps are one of the key equipment of EGS power plant in the Upper Rhine Valley. Unfortunately, the supplier of the first generation pump assembly could not offer an appropriate technical solution for operating conditions in the Soultz wells. Thus, it was decided to develop a new pump adapted to these conditions. This would require a pump of smaller diameter (8 inch) and the use of materials capable of working for extended periods at the expected temperatures in the now thoroughly investigated aggressive geothermal fluids found at the site.

3.1 GTV pump designed by a German company

3.1.1 Design, casting and testing the new GTV pump stages

The GTV pump has been developed on the basis of the manufacturer's electric submersible borehole pumps (ESP). For more than 50 years, this pump type has been successfully employed in a wide range of applications from the water, to the oil and gas industries, and has provided reliable service under particularly demanding pumping conditions as found, for example, in mining operations.

After defining the hydraulic parameters, such as flow rate, head, inlet pressure and the required system pressure, it was necessary to look at the pump assembly's geometry in order to define the greatest possible diameter, which could fit into the pump chamber casing in the production well GPK-2. Finally, the supplier's "200 series" was selected for use as the basis for design adaptation. The pump assembly was matched to the existing lineshaft/production column assembly. Practical experience, combined with a thorough evaluation of the geothermal brine in the materials laboratory of the German company enabled the materials for the geothermal pump components to be chosen: stator bowls and impellers were designed and cast in Duplex alloy (EN 1.4517).

The operational conditions at Soultz implied a need for a larger impeller axial clearance in the stator bowls, so up to 40 mm were defined jointly with the design engineers. Figure 6 presents a drawing of one pump stages developed. To obtain this large axial clearance, it was necessary to extend the impeller necks and adapt the stage casings' length accordingly. In order to cater for all operating parameters, the pump has been designed with a total of 21 stages. As the production of very long, thin shafts complying with the required run-out tolerance would have been very expensive, the bowl unit has been designed with a split shaft. The split is provided between stages 10 and 11. The coupling required to connect both shafts is radially supported in its own intermediate stage and designed as a shaft bearing (Reder et al., 2013). Each impeller is positioned and fixed on its shaft conventionally by means of spacing sleeves, as is conventional in most of water pumps.

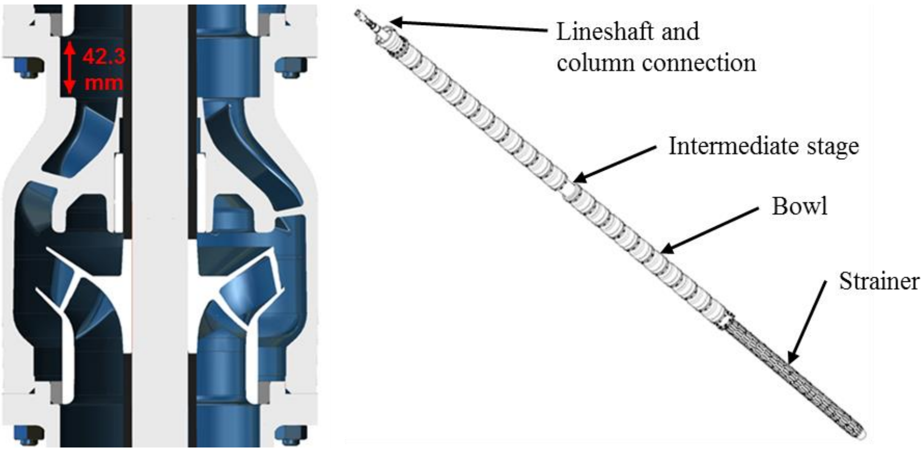

Figure 6: Cross section of one GTV pump stage and drawing of the GTV pump assembly with 21stages

The GTV pump assembly was designed and produced in only 3 months. It was then installed in December 2012 into an 18 m deep test well. Three column units were installed with the GTV pump assembly, the bottom of the strainer being at 16.3 m depth. The lineshaft lubrication system was not required for such a short installation. The lineshaft bearings could be directly lubricated with pumped water. The pump was tested at full speed, i.e. 2 992 rpm, with a control valve connected to its discharge head to control the flow. Impellers were adjusted in their highest position, at +39.5 mm. Motor currents, voltage, power factor, power consumption, vibration, discharge pressure and flow were all monitored at different flow rate from 0.0 to 47.0 L/s. Peak pump efficiency is around 72%, at 33.4 l/s and Total Dynamic Head (TDH) around 325 m (Ravier et al., 2013). The efficiency is lower than that of the ESP original from which the new geothermal pump is derived, this having peaked at around 80%. The difference is due to the increase in axial clearance from only 10 mm to 42.3 mm for this special geothermal GTV pump assembly. Larger impeller clearance induces increased fluid recirculation and frictional losses in the diffuser. However, efficiency is still good and comparable to the initial pump used for the first LSP installations in Soultz, despite having twice as much clearance. Figure 7 shows the performance curves of the GTV pump assembly and a picture of the LSP installed in the well test at the manufacturer's facility.

3.1.2 Operating the new GTV pump

After the successful test, it was planned to install the new GTV in GPK-2. Due to the bad experience with internal design of the lineshaft bearing, it was decided to install the LSP with the standard Icelandic Teflon bearing, because they had given the best result in operation. The installation started at the beginning of January 2013 and lasted for 5 days. A total of 95 shaft elements were installed, implying that the setting depth of the driveshaft/production column assembly was around 289 m, the pump's suction inlet to the first stage being at 294 m depth in the well. Then GPK-2 was reactivated and artesian production restarted in the middle of January.

After warming up the lineshaft with artesian production, tensioning the enclosing tube and adjustment of pump assembly impellers, the LSP was started on the 17th of January 2014. The first step was done at a motor frequency of 20 Hz. As vibration, torque and currents were all normal the frequency was increased to 37 Hz, geothermal production was around 82 m^3/h and well head pressure around 20.5 bar. At this operating point, head developed by the pump was around 217.5 m, which was well in accordance with the manufacturer hydraulic test, giving for this point 220 m, the difference being due to pressure losses in the column assembly. Motor vibrations were measured between 0.3 and 0.4 mm/s and the motor torque around 40% of its nominal value. The commissioning of the LSP was considered successful and motor frequency was reduced to 30 Hz, the minimal operating frequency recommended by the manufacturer. Following commissioning, the LSP ran continuously at 30 Hz for nearly 6 months. It was stopped once only for a short time because of an electrical grid failure, but restarted without any problem.

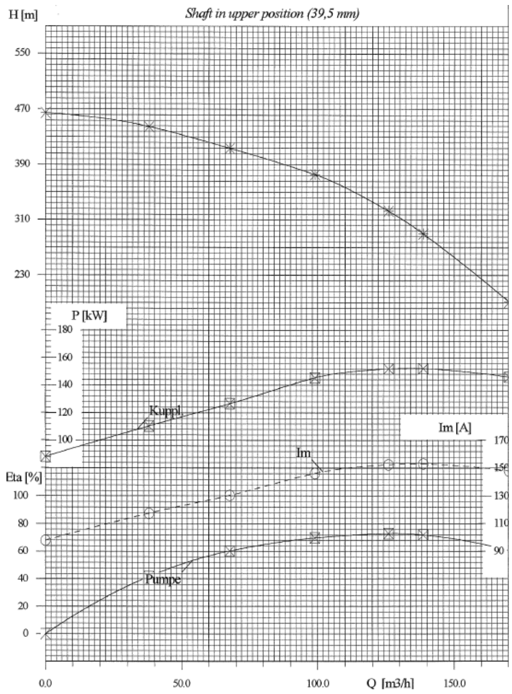

Figure 7: Performance curves of GTV pump assembly at 50 Hz and view of the LSP installed in the test well

During the operation period, Soultz scientist team was leading some corrosion investigation on the new designed pump materials. Two samples of the Duplex alloy and tin bronze prepared according to the ASTM standard were tested in the high temperature skid (Scheiber et al., 2013) on the power plant. After 6 weeks of exposure, Duplex alloy samples didn't show any sign of general or pitting corrosion, whereas bronze material was covered by some general layer of corrosion. Soultz technical team followed closely the LSP's operating parameters, the water level drawdown and the lubrication water treatment because it had been the source of the first pump failure. Sampling the lubrication water revealed dissolved oxygen and carbon dioxide in the lubrication water. The sulphite reaction used to eliminate the oxygen seemed to be quite low at the temperature of the lubrication water (~15°C). This means that lubrication treatment still required some improvement to be able to guarantee reliable operation of the LSP: for example, using a thermal degasser.

Nevertheless, lubrication treatment was not the reason for stopping the LSP at the beginning of July 2013. Indeed, at the end of June, after more than 5 months of operation, a sudden instantaneous drop in pressure of 2 bar and in production flow rate of 3 m^3/h was observed. Surprisingly, motor current increased at the same time by around 10 A, which is not expected when pressure and flow both decrease. Ten days later, a second instantaneous drop in both pressure and flow rate of 5 bars and 10 m^3/h respectively, was observed, accompanied by a significant peak in the vibration signal. In Figure 8 the operating curves of the second of these events are to be seen.

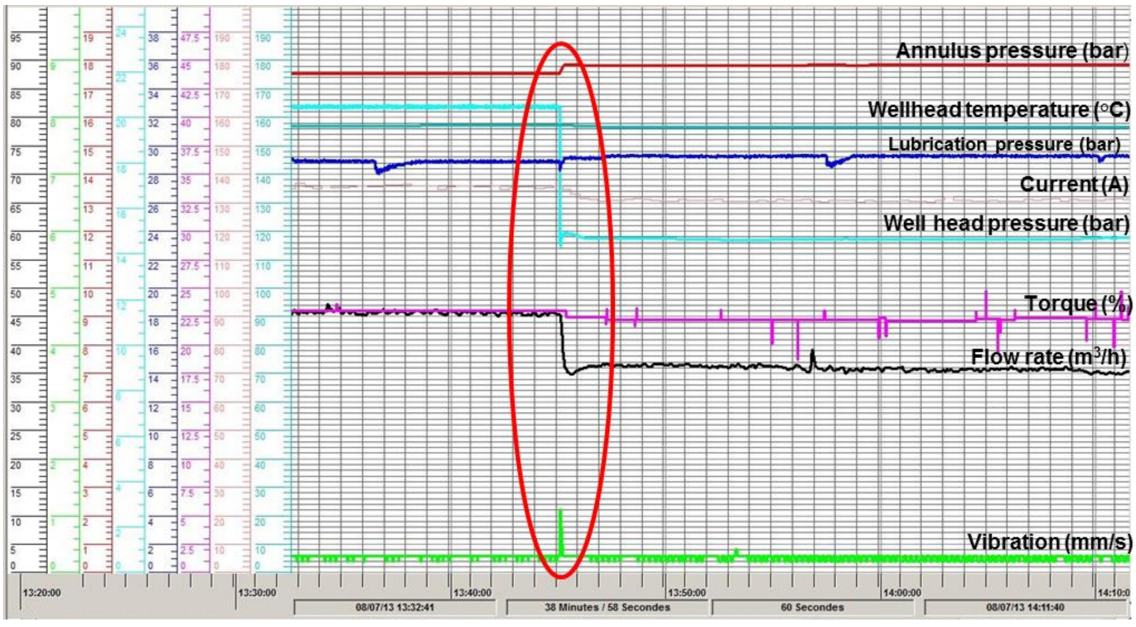

Figure 8: Operating curves of the LSP on the 8th of July 2013

After the second drop, it was decided to measure the wellhead pressure by completely closing the wellhead valve. The aim of this test was to check the hydraulic performance of the pump and compare it to the performance test curve. This led to the suspicion of a leakage in the production pipe and it was decided to cease operation and, as quickly as possible, to remove the pump from the well.

3.1.3 Main observations after 6 month of operation

Pump withdrawal and lineshaft disassembly were very informative. First, a fine layer of iron oxide was observed at the surface of the lineshaft. This layer was particularly present on the shaft elements closest to the surface. The accumulations of these deposits at the top of Teflon bearings created significant wear, sometimes rather severe, on the shaft sleeves. On the left side of Figure 9 is a view of the iron oxide and particle layer on the lineshaft and on the right side can be seen examples of the wear on the shaft bearing sleeves. This confirms that the lubrication water treatment needs to be improved in order to remove more effectively the dissolved gases such as oxygen or carbon dioxide.

Figure 9: View of oxide and carbonate layer on the shaft (left) and of wear observed on several drive shaft bearing sleeves (right)

The leakage in the production column was finally found at the end of the pump withdrawal: two holes of between 3 and 4 cm diameter were observed on the production tube, where it was connected to the top of the pump assembly. Figure 10contains a view of the leaking production column connected to the pump and another after pipe cutting and separation. Investigation of the carbon steel pipe in contact with the Duplex alloy has revealed severe mass loss corrosion. This corrosion is thought to be galvanic corrosion induced by the high electrode potential difference between the Duplex material and the carbon steel and probably the use of inappropriate grease for high temperature brine. In such a saline environment, a galvanic isolation between the pump assembly and the column assembly seems to be required. A further possibility is to make the discharge casing of the pump assembly from an intermediate material to reduce the effect of a high electro-potential difference between carbon steel and Duplex alloy in direct contact. This change is to be discussed with the pump manufacturer and their metallurgy experts.

Figure 10: View of the production tube connected to the pump assembly before dismantling (left) and after (right)

Once pump withdrawal was achieved, the bottom stage (suction) and top (discharge) impellers were water cleaned and could be inspected. No visible corrosion was observed on these impellers, thus confirming the results of corrosion tests made with the Soultz high temperature skid. Moreover no wear could be felt by hand on the impeller necks. In addition, their external diameters were measured and compared with the nominal value. Measurement gave 116.6 mm for the top impeller and 116.7 mm for the suction impeller, strictly in agreement with the nominal value of 116.5 +/- 0.5 mm. The Duplex alloy used for casting the pump components seems to be suitable for the highly corrosive brine of Soultz and for standing up to abrasion due to cuttings carried up from the deep reservoir. The top stator bowl was also inspected carefully, especially since the tin bronze bearings had shown strong corrosion during the corrosion tests. A black layer of general corrosion was found covering the bearing surface and further investigation is required to confirm the material choice (see Figure 11).

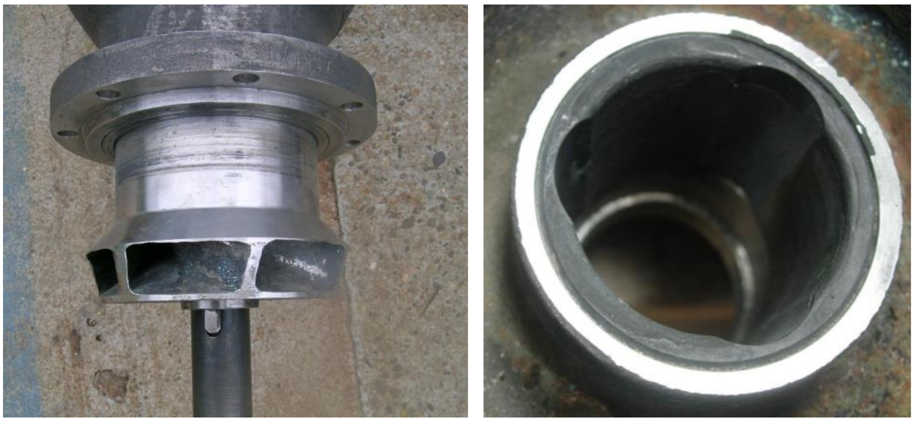

Figure 11: View of the top impeller after cleaning (left) and of the top stator bowl bearing (right)

A measurement of the impeller-to-stator axial clearance of the top (discharge) stage gave a value of 39.0 mm. Nominal value is 42.3 mm. The difference underlines the need for completely dismantling the whole pump in order to clean and inspect all the parts. Unfortunately, the design of the GTV pump with shaft sleeve inherited from the original ESP pump prevents a rapid strip-down, because of scaling deposits between the shaft and its sleeves. This operation requires specialized techniques and personnel and unfortunately until now it has not been possible to plan the complete disassembly, because of the need to establish acceptable procedures for dealing with trace deposits of naturally occurring radioactive material (Cuenot et al., 2015).In the next phase of pump development, such maintenance aspects need to be taken more into consideration from the design stage onwards.

3.2 Pump development with local foundries

<u>3.2.1 Design and casting</u>

Design and material selection of this second pump is based on the knowledge won at Soultz, on LSP experiences in the US (Ellis, 1998) and on seawater pump experiences. Thus, the bowl unit was designed with thrust balanced and unbalanced impellers with 40 mm of axial clearance to ensure good management of thermal and mechanical shaft elongation under load. In order to reduce erosion and abrasion effects, the design pump speed was reduced from 2900 rpm to 2400 rpm and the stator bowls were equipped with built-in “sand lugs” extending axially out from the end of the stator housing and lying close along the outside of the impeller neck to catch sand and sediments. Unlike the GTV pump, the impellers of this new pump are located and fixed on the shaft with collets for ease of maintenance in the presence of scaling, even if sleeves are normally regarded as a safer method. The suitability of this choice for Soultz brine was confirmed after the 6 months of operation of the GTV pump assembly. Due to the low design speed, 20 stages were required to match the specified hydraulic parameters, with 10 thrust balanced impellers and a split shaft. Figure 12 presents a view of the 3D model of one thrust balanced stage and the expected pump curve at 2400 rpm.

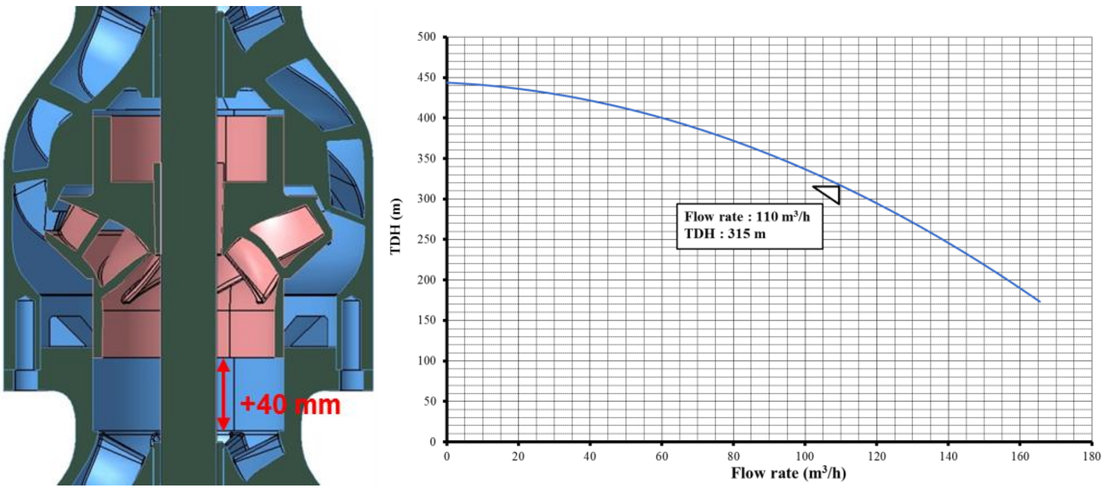

Figure 12: View of the 3D model of on thrust balanced stage and expected pump curve at 2 400 rpm.

Concerning the material, a tin bronze impeller was tested in Soultz from 2008 to 2010. It was completely covered by a general layer of corrosion, but unlike cast iron it was not damaged by erosion and abrasion. Material choice of impellers was based on this experience and seawater pump: a nickel aluminium bronze was selected because of the hard, resistant surface corrosion layer, which occurs in a brine environment. For the stator bowl, a cast iron alloy (EN GJS 800-2) was selected for reasons of casting cost and to avoid galvanic corrosion with the column unit. The pump assembly was designed with nickel-bronze/uncoated 17-4PH shaft technology. Two local foundries were contracted to undertake the casting of impellers and bowls, using sand casting. Figure 13shows on the left a picture of the exterior of the resin-bonded pattern form for the outside sand mould for the stator bowl and on the right the core ready formed in sand for insertion into the mould to give the inner stator form.

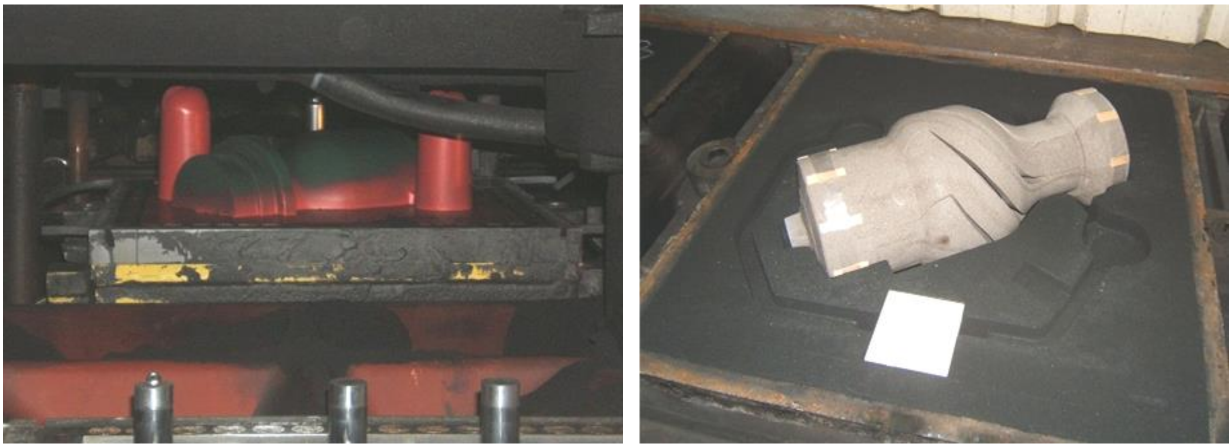

Figure 13: View of the outside resin-bonded form for the casting mould used for the stator bowl (left) and of the sand inner mould (right).

The pump components are in production. Some are already cast and machined. Manufacturing has demanded more time than planned because the foundries required several iterations in making the resin pattern, catering for the 3-dimensionalform models. Next step of this bowl unit development was to test it previously to its installation into a GPK-2. Unfortunately, the column unit of Soultz LSP is not yet available for such installation because of the last operating LSP: a complete new column unit is required for a new operation.

3.2.2 Modal analysis of the Soultz LSP

In order to understand better the frequency behaviour of the Soultz LSP, and especially its natural modes, a 3-D CAD model of the pump was done with the University of Strasbourg. This model was implemented with CATIA (V5 R20). This software was selected because of its user-friendly graphical interface and its integrated finite element set-up and calculation modules. All pump parts of the LSP, including surface equipment (pipes, pump supports, motor…) were modelled. First of all, a dynamic modal analysis of the 3-D model pump was compared to vibration measurements made on-site in 2008. Then, the influences of installation depth and well deviation were analysed. The aim here was improving the design of the LSP by eliminating, as far as possible, natural frequencies in the operating frequency range of the pump, 30 to 50 Hz. In Figure 14 a view is shown of the 3-D model of the LSP and the consequences of the natural modes at around 33 Hz, associated with torsion and distortion of the electrical motor support structure. This study has indicated that reinforcing the wellhead against shear forces would remove all natural frequencies between 30 and 50 Hz.

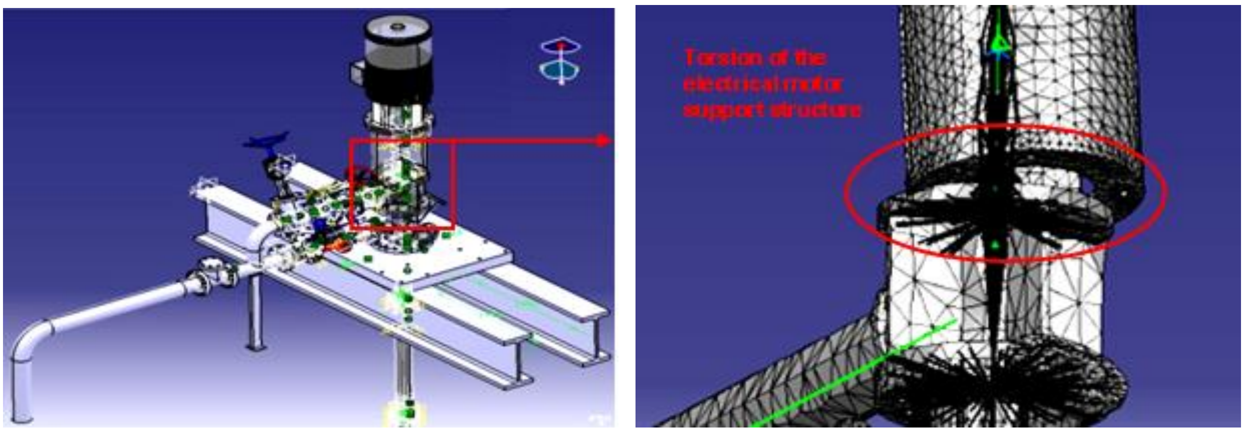

Figure 14: View of the 3D model of the LSP and consequences of the natural modes at around 33.2 Hz

4. CONCLUSION

Unlike EGS projects at nearby sites in the Upper Rhine Valley, such as the Landau and Insheim geothermal power plants, it was not possible to install a standard US LSP (Frost, 2010) because of the limited diameter of the pump chamber in the production well, which had been built for research purposes. Standard US LSP’s are designed for operation in $13^{3/8}$inch casing, while the GPK-2 well pump chamber was conceived and completed using $9^{5/8}$ inch casing. Thus, the first LSP installed in GPK-2 at Soultz in 2008 was a standard Icelandic 8 inch water-lubricated LSP. From 2008 to 2013, the Soultz LSP in GPK-2 was installed and removed seven times because of the highly aggressive Soultz conditions compared to Iceland. In Table 1 below, a summary of the different installations, the running times and the causes of failure is presented. Most of the failures are related to abrasion and corrosion damage to pump and lineshaft/production tube components, although lubricating water quality was an additional factor.

Table 1: Summary of the different installations, running times and causes of failure from 2008 to 2013

N°	Date of Installation	Installation depth	Operating time	Cause of pump failure	Date of removal	Comments
1	May 2008	350 m	2 months	Breakdown of the lineshaft due to carbonate scaling	August 2008	Standard Icelandic assembly Lubrication by drinking water
2	September 2008	250 m	4 months	Lineshaft blocking after electrical grid failure	June 2009	3 new impellers (1 cast iron, 2 tin bronze) Softened water lubrication
3	October 2009	260 m	11 months	No failure: Maintenance and expertise	October 2010	Complete new pump (all cast iron, except the 2tin bronze impellers) 25% redesigned Teflon bearings Rev. osmosis cleaned lubricating water
4	November 2010	260 m	4 months	Decrease of production due to corrosion and erosion	April 2011	50% redesigned Teflon bearings
5	August 2011	265 m	2,5 months	Low enclosing tube tensioning leading to stress corrosion and leakage of the enclosing tube	November 2011	Complete new pump (cast iron) 100% redesigned Teflon bearings
6	March 2012	250 m	5 days	Lineshaft blocking probably due to high corrosion-erosion of bowls and impellers	May 2012	New impellers 100% bronze bearings
7	January 2013	295 m	6 months	Production column leakage	July 2013	Complete new pump assembly (Duplex alloy) Standard Icelandic Teflon bearings

Even if the new GTV pump assembly is adapted to the highly aggressive Soultz conditions, operation of the LSP without a reliable lineshaft column could not be sustainable. The last LSP operation with the GTV pump assembly in 2013 has shown the limit of the actual water treatment (osmosis with sulphite). To continue using water-lubricated Teflon bearings, it will be necessary to add a thermal degasser before injecting the lubrication fluid at the top of the lineshaft assembly, in order to be sure that no oxygen or carbon dioxide can cause corrosion in the lineshaft column. This would increase the operating cost, as well as the failure risk. Another possibility could be to replace the water by oil lubrication. This has been used successfully in the United States since the 1970's.Environmental impact and administration permission for oil lubrication are under investigation.

It is thus clear that further developments with pump manufacturers are essential to be able to guarantee reliable operation of the EGS Soultz power plant. It has also become clear that maintenance aspects have to be considered from the start of pump and production column design for facilitating servicing during the equipment's entire operational lifetime, using engineering techniques and work procedures adapted to the typical types of scaling and deposits experienced in the Upper Rhine Valley.

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