Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Flexible Couplings for Improved Casing Design in High-Temperature Geothermal Wells

Ingolfur O. Thorbjornsson, Gunnar S. Kaldal

ISOR-Iceland GeoSurvey, Grensásvegur 9, 108 Reykjavik

Ingo@isor.is

Keywords: casing design, casing collapse, buckling, thermal expansion, flexible couplings, GeoWell, DEEPEGS

ABSTRACT

A new approach, Flexible Coupling (FC), aimed at reducing the risk of plastic deformation and failures of casings has been developed and laboratory tested in the EU funded project GeoWell (www.geowell-h2020.eu). This approach allows for axial thermal expansion of casing segments, which is one of the major concerns in the operation of high-temperature geothermal wells and relates to structural damages during warm up and discharge after drilling. Wells are constructed of several casings with different outer diameters and depths. The innermost casing is subject to high stresses due to thermal expansion that can lead to plastic deformation when used in constrained conditions, which increases chances of casing failures. The casings are made of steel grades, chosen according to standards API 5CT and ANSI/NACE MR0175/ISO 15156. Medium carbon steel commonly used for geothermal casings have thermal expansion coefficient around 0.012 mm/m°C. Therefore, casings that are cemented in at cooled temperatures are subject to high stresses during warm up and production. Casing connections have larger outside diameters than the casings, which means that the connections are anchored in the cement, therefore free axial thermal expansion of the casings is constrained. The new concept of Flexible Couplings is to enable axial elongation of casing segments at the connections. It has been designed and built, tested for sliding and repeatability of sliding, pressure tested up to 165 bar and finally the tensile strength to failure has been verified against numerical models. The new concept is designed to minimize plastic strains caused by constrained thermal expansion. Therefore, the risk of casing tensile failures because of subsequent cooling, e.g. during workovers, is reduced considerably. No extra tools, training nor extra work is needed at the drill rig. Running in casings made up with the new connections is therefore carried out with the same procedures as common casing jobs. This paper focuses on the testing results in third party laboratories and the status of this emerging technology.

1. INTRODUCTION

The concept of Flexible Coupling (FC) was first introduced 2015 as the first patent application was delivered. First by tests conducted in two *third party* testing laboratories at ambient temperatures and by full scale surface testing at production temperatures and pressures. The design criteria for the FC is to fulfill all requirements for drilling, cementing and completion of the geothermal well, meaning that the anchor casing and diameters of drill bits are the same as conventionally used with additional sliding capability of the connections of the production casing. The risk of tearing the casing out of couplings during cooling, e.g. for well workovers, can be lowered significantly with the use of FC. Additional benefits of reducing the axial stress to the elastic range of the material, could be reduced expected risk for buckling/collapse because of limited plastic strains that cannot be controlled in conventional casing systems for high-temperature geothermal wells. Axial displacement, designed according to the difference between cementing temperature and operational conditions, can be adjusted to operational temperatures up to 600°C with the aim to reduce axial stresses down to about 60-70% of the yield stress of the given material for production casing.

European Union Horizon 2020 research and development program has funded two projects (www.geowell.eu, www.deepegs.eu) where the FC has been designed, tested and verified. The next step is final tests in laboratory of up to three more full scale FC, followed by production of FCs for full length of a production casing for a new geothermal well. Additionally, full scale surface testing of cemented in FC is constructed and planned to be tested late 2019 in the EU funded Geothermica project (www.geothermica.eu) GeConnect (Kaldal et al. 2020). The plan is to have it ready for a high-temperature well in Iceland by the end of the year 2020 and this full-scale in-situ test is already funded through the DEEPEGS project.

2. DESIGN

The main function of the FC is to mitigate the axial thermal load in the production casing. The axial load is caused by constrained thermal expansion of the material in the casing during warm up from cementing temperature to operational temperatures. Cementing temperatures, are the initial conditions of constraints of the casing and can vary from over 100°C in the bottom of the well to around ambient temperatures at the top. This function of the FC allows each casing segment of approximately 12 m (API 5CT standard range 3) to expand axially into the FC at one end of the segment, thereby enabling design where the stress level of the casing material is controlled to be lower than the yield strength of the material, preferably around 60-70% of the yield for the given material (K55 or L80). This enables the possibility to design geothermal wells following the same design criteria as used for surface installations, i.e. to be designed elastically. The allowed axial movement is according to expected temperature in the well and more specifically temperature difference between cementing temperature and operational temperature. FCs are therefore in the beginning designed in, but not limited to, several temperature intervals as shown in Table 1. Design work and related parameters have been reported by Kaldal et al (2011), Kaldal and Thorbjornsson (2016) and Thorbjornsson et al (2017). Full-scale tests described below are valuable for validation of Finite-Element (FE) models that for further design decisions have already led to improvements in the design, e.g. to minimize stress and strains in the connection, see the work flow of such analysis in Figure 1.

Table 1: Table showing proposed temperature intervals for the Flexible Couplings.

	Operational temperature [°C]
Flexible Coupling 200	200-300
Flexible Coupling 300	250-350
Flexible Coupling 400	300-400

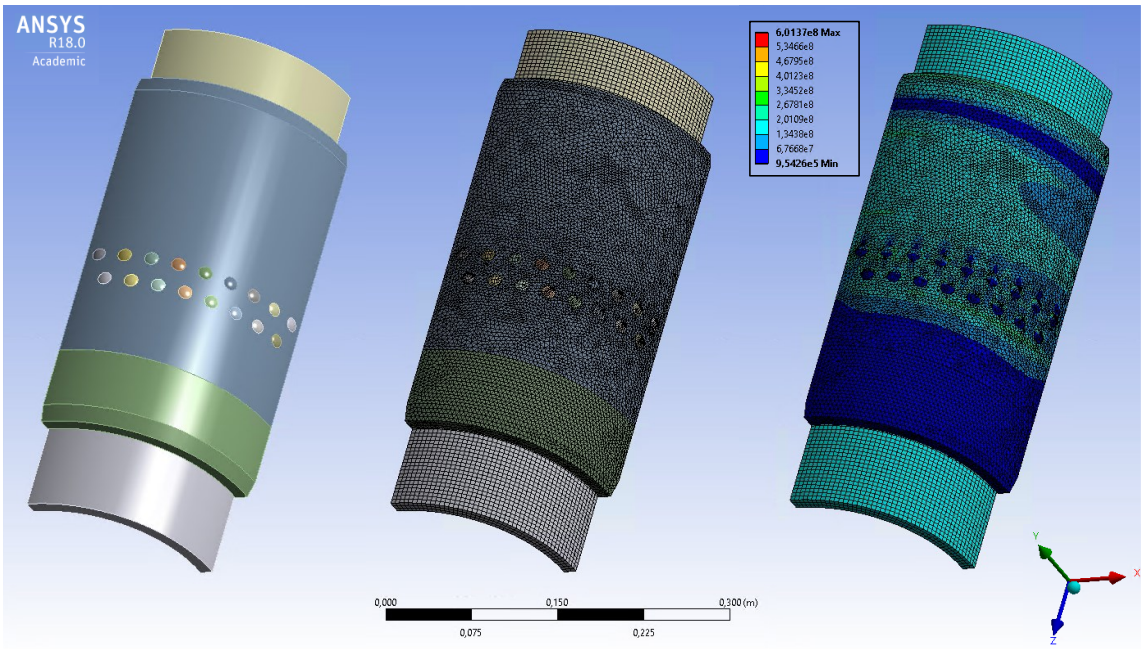

Figure 1. FE analysis in Ansys Mechanical was used during the design of the Flexible Coupling, taking into account non-linear material properties for plastic analysis. The geometry, designed using Ansys Spaceclaim, was meshed in Ansys Mechanical where the analysis is performed and structural solution retrieved (Kaldal and Thorbjornsson, 2019).

3. TESTING OF THE FLEXIBLE COUPLINGS

FC prototypes were made for testing in two casing dimensions, 9⅝″ and 13⅜″. The prototypes used for testing purposes were made of medium carbon steel type AISI 4140, equivalent to and commonly known in the geothermal industry as L80. First three full scale tests were performed under supervision of Equinor in the GeoWell project at SINTEF (www.sintef.no) laboratories in Trondheim, Norway, of the 9⅝″ casing size, and one 9⅝″ and one 13⅜″ prototype were tested at NORCE (www.norce.no) laboratories in Stavanger, Norway. Test setup in SINTEF and NORCE can be seen in Figure 2 and Figure 3, respectively. The test procedure, based on the ISO/PAS 12835:2013(E) testing standard for premium connections was adjusted to testing FC as the standard is not intended for connections with moving parts. The main goal of the testing was to verify the sliding capability of the FC and forces needed for sliding. An important part of the tests was to verify the repeatability of the sliding both in straight and deviated conditions, determine the leaking from internal water pressure testing and finally to measure the ultimate tensile strength of the FC.

3.1 Testing FC in 9⅝″ casing size

For the 9⅝″ FC prototypes tested, the testing loads were selected as 1000 and 2000 kN in compression, and 1000 kN in tension (Figure 2). In all load cases as well as in unloaded open and closed position, pressure tightness with water at ambient temperature was measured. Sliding forces and start up force for sliding were measured in both straight and bended position. For the first three prototypes in 9⅝″ a bending curvature of 2,5°and 5° pr. 30 m length was applied and sliding forces during bending measured. Finally, the ultimate tensile load capacity was measured by overloading the FC until failure. For the testing of the fourth prototype it was decided to skip the curvature testing as the sliding force had shown to be constant in all three previous tests.



Figure 2: Testing of 9⅝″ Flexible Coupling in SINTEF laboratories in Norway.

3.2 Testing FC in 13⅜″ casing size

Test loads for the first 13⅜″ FC prototype tested were selected as 1400 and 2800 kN in compression (Figure 3). As deviation from the testing of the 9⅝″ FC it was decided to test water leakage only in compression. Due to defect in machining of the flexible side, leak was detected and accordingly therefore the leak testing was only measured at compression loads. Startup force and sliding force was measured and repeatability verified.

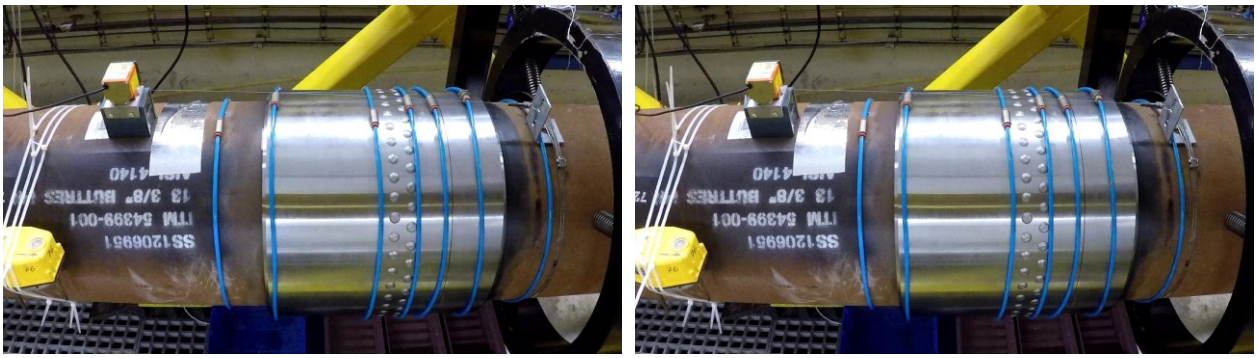

Figure 3. Testing of 13⅜″ FC in NORCE laboratories in Norway. On the left fully open unloaded FC, on the right fully closed FC. Movement shown 20 mm.

For full scale testing in high temperature geothermal well in Iceland further testing of the 13⅜″ FC is scheduled late 2019. If successful, there further planned production of FC for full production casing string for in well demonstration in Iceland scheduled in February/March 2020. Table 2 shows result from testing three 9⅝″ FC in SINTEF, one 9⅝″ and one 13⅜″ in NORCE.

Table 2: Test result of 5 FC prototypes at SINTEF (Prototype 1-3) and NORCE (Prototype 4 and 5). Sliding forces in bending only performed on prototype 1-3.

Prototype:	Start force [kN]	Sliding force [kN]	2,5° bending: Sliding force [kN]	5° bending: Sliding force [kN]	Ultimate tensile load [kN]
1 - 9⅝	200	200	200	200	1837
2 - 9⅝	300	300	300	300	1926
3 - 9⅝	320	320	320	320	3135
4 - 9⅝	247	176-219	-	-	3032
5 - 13⅜	267	189-229	-	-	3922

4. CONCLUSION

Testing of five prototypes of Flexible Couplings have been performed, whereof four tests for 9⅝″ casing diameter and one for 13⅜″ casing diameter. Results show that the concept of the FC with sliding mechanism is working well, for straight as well as deviated test setup. Sliding forces have been recorded and are consistent during several runs of opening and closing the couplings. Sliding forces have been slightly adjusted between prototypes as well as improvements to the ultimate tensile strength. Leakage has been recorded to be over given limits by the standard for premium connections. Part of the improvements between prototypes have been focusing on pressure tightness of the FC. Prototype 4 in 9⅝″ casing diameter showed pressure tight connection in all positions tested up to 110 bar water pressure at ambient temperature. Two international patent applications have been filed to the European and USA patent agencies, both have now been accepted as Icelandic patents. The schedule for the next steps in the verification process is to test 3 additional prototypes of 13⅜″ diameter and thereafter the plan is to make a full-scale demonstration by producing up to 100 pcs of 13⅜″ FC for the production casing in a well to be drilled in Iceland at the Reykjanes geothermal field early 2020.

ACKNOWLEDGEMENT

The authors would like to express our gratitude to the European Commission for the support in the H2020 projects GeoWell under grant agreement No 654497 and DEEPEGS under grant agreement No 690771.

REFERENCES

Kaldal, G.S., Jonsson, M., Palsson, H., Karlsdottir, S.N., Thorbjornsson, I.O., "Load History and Buckling of the Production Casing in a High Temperature Geothermal Well" *Proceedings: Stanford Geothermal Workshop*, Stanford, CA (2011).

Kaldal, G.S., and Thorbjornsson, I.O., "Thermal expansion of casings in geothermal wells and possible mitigation of resultant axial strain". *European Geothermal Congress*, Strassbourg France (2016).

Kaldal, G.S. and Thorbjornsson, I.O..: The Horizon 2020 Project DEEPEGS: Deliverable 5.6: Design of flexible coupling for use in higher temperature deep geothermal wells; Reykjavík: ÍSOR – Iceland GeoSurvey, 2019.

Kaldal, et al., "Thermal Stress Mitigation Testing of Externally Cemented Flexible Coupling in Geothermal Steam". Proceedings World Geothermal Congress 2020.

H. P. Lohne, E. P. Ford, M. Mansouri Majoumerd, E. Randeberg, S. Aldaz, T. Reinsch, T. Wildenborg and L. G. Brunner, "Barrier definitions and risk assessment tools for geothermal wells," GeoWell, Stavanger, 2017.

Thorbjornsson, I.O., Kaldal, G.S., Gunnarsson, B.S., Ragnarsson, A., "A New Approach to Mitigate Casing failures in High Temperature Geothermal Wells", *Geothermal Resources Council 41st Annual Meeting*, Salt Lake City (2017).