Task 3.1

Title

Innovative technologies

Projects (presented on the following pages)

DuoTurbo: Mechanical Design
D. Biner, S. Luisier, L. Rapillard, L. Andolfatto, V. Berruex , V. Hasmatuchi, F. Avellan, C. Münch-Alligné

Workflow for managing deep deviated geothermal well stability
A. Dahrabou, B. Valley, F. Ladner, F. Guinot, P. Meier

Understanding the unstable off-design operation of Francis turbines for large scale NRE integration
A. Favrel, K. Yamamoto, A. Müller, F. Avellan

Prediction of hydro-acoustic resonances in hydropower plants operating in off-design conditions
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Performance assessment of a new kinetic turbine prototype
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Empirical models for Francis turbine performance estimation
J. Gomes, L. Andolfatto, F. Avellan

Impact of polymers in well cementing for geothermal wells
M. Palacios, R. K. Mishra, D. Sanz-Pont, R. J. Flatt

Extension of Francis turbine Operating Conditions by Controlling the Part Load Vortex Rope
S. Pasche, F. Gallaire, F. Avellan

Development of an experimental protocol to assess the new kinetic turbine performance
S. Richard, A. Gaspoz, V. Hasmatuchi, N. Brunner, S. Chevailler, C. Münch-Alligné

Expected Corrosion Issues in Geothermal Power Plants in Switzerland
A. Vallejo-Vitaller, U. Angst, B. Elsener

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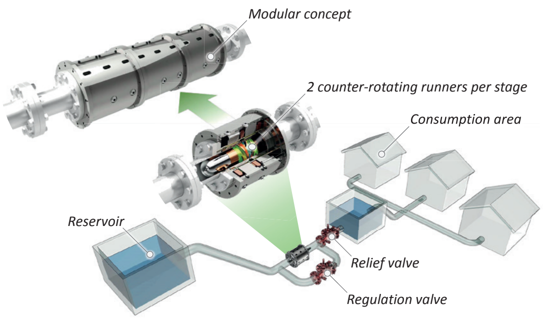
DuoTurbo: Mechanical Design

D. Biner [1], S. Luisier [1], L. Rapillard [1], L. Andolfatto [2], V. Berruex [2], V. Hasmatuchi [1], F. Avellan [2], C. Münch-Alligné [1]
[1]HES-SO Valais//Wallis, School of Engineering, Hydroelectricity Group, Sion, daniel.biner@hevs.ch
[2]EPFL, Laboratory for Hydraulic Machines, Lausanne

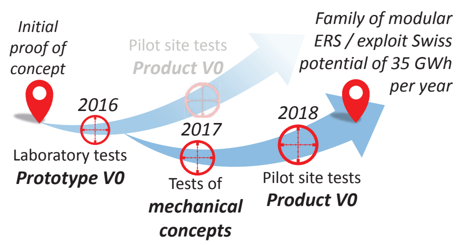
Context

- Recovering hydraulic energy lost in **drinking water networks**
- Modular in-line "plug and play" turbine from **5 to 25 kW**
- No environmental impact
- Low investment costs



Project

DUO TURBO



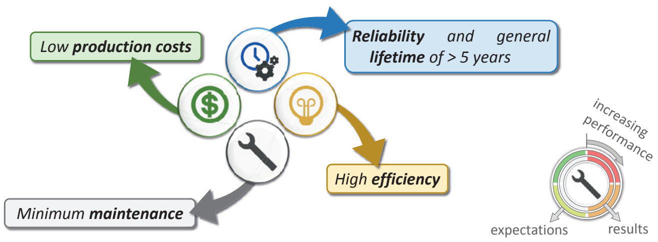
Technical challenges

The hydraulic and electrical concepts of the DuoTurbo prototype have successfully been validated by laboratory tests in 2016. The main issue that is still not entirely resolved, concerns the mechanical concept of the runner bearings. The given operating conditions and requirements make it difficult to find suitable technical solutions.

Operating conditions

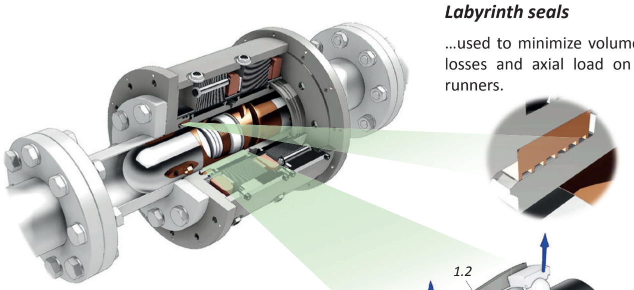
- High **axial forces** > 3 kN possible
- High **rotational speed** up to 3500 min^{-1}
- Pipeline **pressure** > 20 bar possible
- Water contaminated with **abrasive particles**

Requirements



Tested mechanical concepts

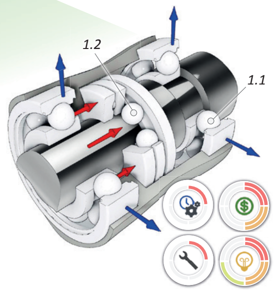
The accomplishment of the given requirements is crucial for the realization of an industrial DuoTurbo turbine. Therefore, different mechanical solutions have been analyzed, designed and tested.



Labyrinth seals

...used to minimize volumetric losses and axial load on the runners.

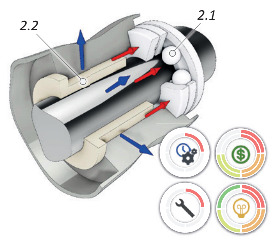
Version 0.1



Concept: Water lubricated radial (*1.1*) and axial (*1.2*) ceramic ball bearings with high corrosion resistance.

Conclusion: Successful for hydraulic and electrical laboratory tests (2016). Enlarged viscous friction and uncertain long time behaviour of submerged ceramic bearings.

Version 0.2



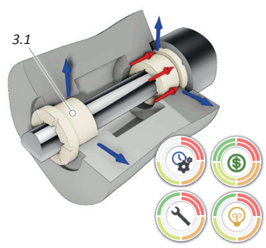
Concept: Water lubricated axial ceramic ball bearing (*2.1*) combined with hydrodynamic radial plain bearing (*2.2*). Reduced mechanical losses and production costs.

Conclusion: Advanced stage of wear of ceramic ball bearings after laboratory tests. Water lubrication insufficient to ensure requested reliability.

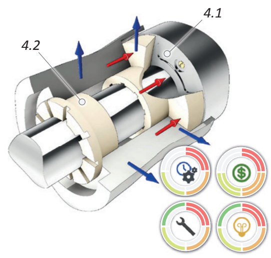
Version 0.3

Concept: Hydrodynamic axial and radial plain bearings *(3.1)*, ensuring low wear, low mechanical friction, low maintenance and production costs.

Conclusion: Different bearing materials and shapes tested on a test rig. Hydrodynamic effect too weak to support axial load of turbine runners. Failure during laboratory tests.



Version 0.4



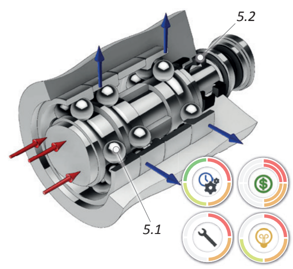
Concept: Axial hydrostatic bearing (*4.1*) and radial hydrodynamic plain bearing (*4.2*), ensuring low mechanical friction, low wear and low maintenance costs. Hydrostatic bearing supplied by water pipeline pressure. Requires considerable precision of mechanical assembly.

Conclusion: Functionality of hydrostatic bearing validated on separate test rig. Low efficiency of labyrinth seals caused failure during laboratory tests, due to underestimated axial forces.

Version 0.5

Concept: Encapsulated, grease lubricated angular ball bearings (*5.1*) guaranteeing requested lifetime and reliability. Tightness ensured by mechanical seal (*5.2*), typically used for pumps. Considerable maintenance costs due to regular replacement of the seal (1-2 years).

Actual state: First laboratory performance tests successful. Endurance test phase ongoing until end of 2017.



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- D. Biner, V. Hasmatuchi, D. Violante, S. Richard, S. Chevailler, L. Andolfatto, F. Avellan, C. Münch, **"Engineering and Performance of DuoTurbo: Microturbine with Counter-Rotating Runners"**, *28nd IAHR Symposium - Grenoble*, July 2016.

Development team of Duo Turbo (CTI Nr. 17197.1 PFEN-IW)

HES-SO Valais//Wallis:
D. Biner, S. Luisier, S. Martignoni, D. Violante , V. Hasmatuchi, S. Richard, C. Cachelin, L. Rapillard, S. Chevailler, C. Münch-Alligné

EPFL LMH:
L. Andolfatto, V. Berruex, F. Avellan

Industrial partners:
Telsa SA, Jacquier-Luisier SA, Valelectric Farner SA

Hes·so Valais Wallis — Haute Ecole d'Ingénierie, Hochschule für Ingenieurwissenschaften
LMH Laboratory for Hydraulic Machines — EPFL École Polytechnique Fédérale de Lausanne
Valelectric Farner SA
Telsa Electrotechnique
Jacquier & Luisier SA Atelier mecanique

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Workflow for managing deep deviated geothermal well stability

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(2) Geo-Energie Suisse AG, Reitergasse 11, 8004 Zürich, Switzerland.

I- Project context and objectives

In the frame of a CTI-project, the CHYN and Geo-Energie Suisse AG are developing a workflow and associated software tools that allow a fast decision-making process for selecting an optimal well trajectory while drilling deep inclined wells for EGS-projects. The goal is to minimize borehole instabilities as it enhances drilling performance and maximize the intersection with natural fractures because it increases overall productivity or injectivity of the well. The specificity of the workflow is that it applies to crystalline rocks and includes an uncertainty and risk assessment framework.

II- Workflow development approach

A sensitivity study performed on data from the well BS-1 (DHM project Basel) showed that the most influential parameters on borehole stability are the magnitude of the maximum horizontal stress, S_{Hmax} the uniaxial compressive strength, UCS, and the internal borehole pressure P_{mud}

2.1- Model calibration

The understanding of borehole failure in deep crystalline well is lacunar because the strength and stress parameters are largely unknown independently. Moreover, there is no agreement on the appropriate failure model required to capture all characteristics of borehole failure

a. Calibration based on simple but consistent failure modeling approach

Different failure criteria were tested and it was shown that the purely cohesive criterion allows getting calibration that is more consistent across the studied failure indicators. This result is consistent with the literature that indicates that breakout formation is a cohesion weakening process.

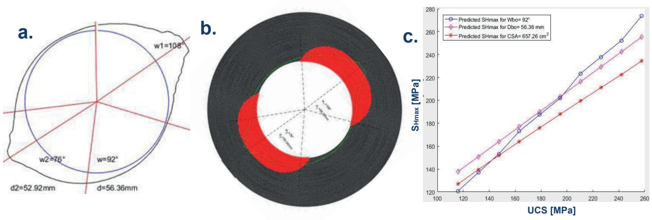

Figure 1. a) Failure observation in BS-1 hole at z=3509m. The blue circle corresponds to the bit size and the black envelop represents the geometry of the well. An average value of w= 92°, d= 56.36mm, CSA= 657.26 cm^2 were observed for breakout width, depth and the cross sectional area respectively, b) Predicted failure using Mohr-Coulomb criterion in a simple elasto-brittle computation, c) Calibrated couples (S_{Hmax},UCS), for a vertical hole at z=3509m using the purely cohesive failure

b. Calibration based on independent data (sonic and density)

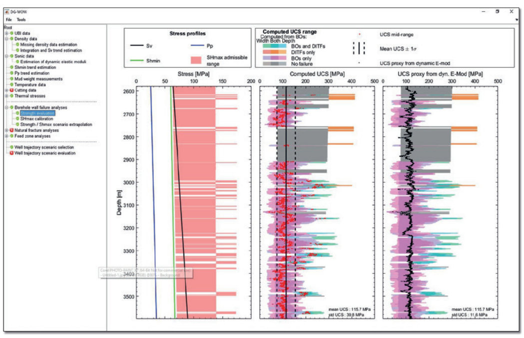

Figure 2. Output from the strength evaluation computations. This evaluation is performed in two main steps: a) realistic parameters ranges are computed based on frictional strength limit of the earth crust and observation of tensile failure in the well, then c) the strength is approximated using strength proxy and the strength/stress couple is calibrated.

- **Extrapolating calibrated strength/stress profiles**

The calibrated SHmax trend and UCS can be extrapolated to larger depth to anticipate condition when extending the borehole. In order to capture the variability associated with SHmax and UCS, a multipoint statistics direct sampling approached is used.

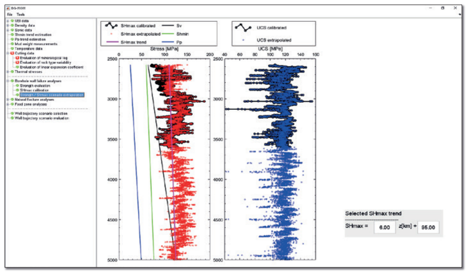

Figure 3. Computed extrapolated profiles of SHmax and UCS

2.2- Selection of wellbore trajectories scenarios

A summary of many decision factor in terms of stereographic projection is presented in order to help selecting potential scenario to be tested

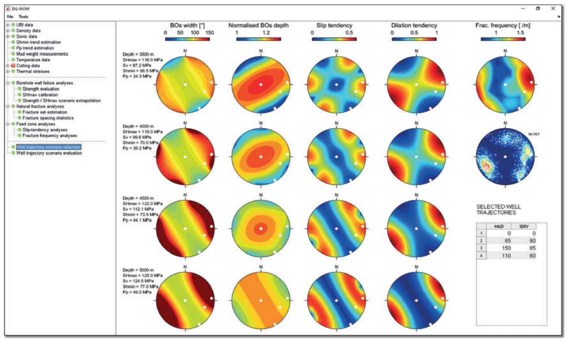

Figure 4. A set of stereographic projections in terms of many decision factors (Breakout width, breakout depth, slip tendency, dilation tendency and fracture frequency) that help selecting potential scenario. These results were performed for depth= 3500m, SHmax= 116 MPa, Sv= 87.2 MPa, Shmin= 66.5 MPa, Pp= 34.3 MPa. Four scenarios with different borehole orientation were selected (white points shown in the stereoplots)

III- Conclusions

- UCS and S_{Hmax} (maximum horizontal principal stresses) are the parameters the most influential on failure computation.
- In combination with an elastic solution for the computation of the stress concentration around the borehole, a purely cohesive failure criterion provides the most consistent prediction across failure indicators
- A pragmatic calibration approach was chosen: firstly, realistic ranges for both S_{Hmax} and UCS were computed based on admissible stress limits and secondly, independent data (sonic and density data) were used as a proxy to approximate the strength

IV- Perspectives

- Further develop the calibration approach adding some additional important parameters like well stability control with drilling mud
- Bring in some more systematic approach in selecting scenario based on identification of key drilling scenario using clustering analyses
- Further test and develop the simple failure model used so far against more advanced modeling approach
- Further test the workflow on existing deep geothermal drilling dataset (Soultz,…) and to new deep geothermal drilling site (Haute-Sorne)

References

Diederichs, M.S. 2007. The 2003 CGS Geocolloquium Address: Damage and spalling prediction criteria for deep tunnelling. Can. Geotech. J., Vol. 44: 9, pp. 1082-1116(35)

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Prediction of hydro-acoustic resonances in hydropower plants operating in off-design conditions

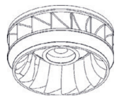
A. Favrel, J. Gomes, C. Landry, S. Alligné, C. Nicolet and F. Avellan

Context


Unsteady power output from renewable energies


Electrical grid is exposed to large fluctuations


Balancing by off-design operation of hydropower plants


High swirl and unstable cavitation flows

Research Project

The **HYPERBOLE** research project (ERC/FP7- ENERGY-2013-1-Grant 608532), consisting of leading European universities and turbine manufacturers, aims at making a decisive contribution towards the smooth integration of NRE by enabling the safe extension of Francis turbines operating range.

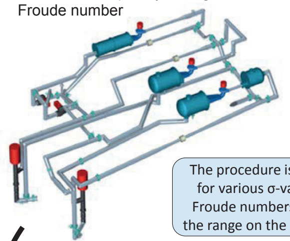
Objectives:

- Develop advanced 1D numerical model of cavitation flows in the draft tube of Francis turbines operating in off-design conditions
- Develop a complete methodology for predicting hydro-acoustic resonances in hydropower plants based on 1D numerical modelling and reduced scale model tests

Methodology

Reduced scale model test in laboratory

✓ Identification of the precession frequency and the natural frequency for a given σ – value and Froude number

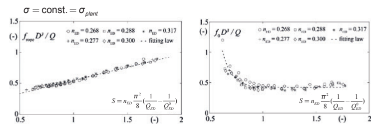


The procedure is repeated for various σ-values and Froude numbers covering the range on the prototype !

~~Direct prediction of resonance conditions~~

Frequencies versus Swirl number

✓ Influence of both the head and discharge on the precession and natural frequencies represented by a single parameter, the swirl number [2]:



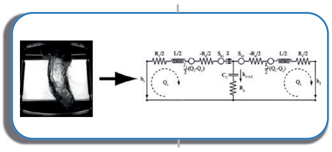
Identification of hydro-acoustic parameters [1]

✓ Wave speed in the draft tube at the model scale as a function of the swirl number:

1D model of hydraulic test rig in off-design conditions [1]

1D simulation model

SIMSEN



1D model of hydropower plant in off-design conditions [3]

Transposition of the hydro-acoustic parameters from model to prototype:

$$a^P = a^M\left(\frac{D^P_{ref}}{D^M_{ref}}\right)\left(\frac{n^P}{n^M}\right)$$

$$\mu''^P = \mu''^M\left(\frac{D^P_{ref}}{D^M_{ref}}\right)^2\left(\frac{n^P}{n^M}\right)^2\left(\frac{f^M_{natural}}{f^P_{natural}}\right)$$

Full-scale hydropower plant

Prediction of resonance conditions on the prototype

✓ Direct transposition of the precession frequency from model to prototype

✓ Computation of the prototype natural frequencies with 1D SIMSEN model of the hydropower plant unit

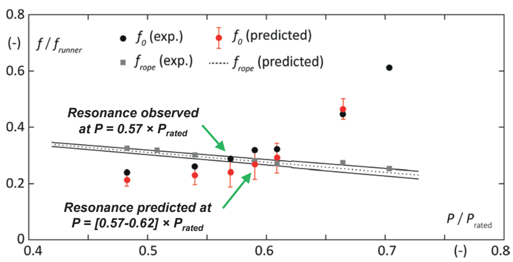
✓ Determination of the output power in resonance conditions, i.e. when $f_0 = f_{rope}$

Hydro-acoustic parameters at the prototype scale

✓ Wave speed in the draft tube at the prototype scale as a function of the swirl number:

Results and validation by on-site measurements

✓ Very good agreement between predicted and experimental values for both the precession and natural frequencies, as well for the output power in resonance conditions



References

[1] Landry C. et al. (2016), «*Local wave speed and bulk flow viscosity in Francis turbines at part load operation*», Journal of Hydraulic Research, vol. 54(2)

[2] Favrel A. et al. (2017), «*New insight in Francis turbine cavitation vortex rope: Role of the runner outlet flow swirl number*», Journal of Hydraulic Research, accepted for publication (in press)

[3] Alligné et al. (2015), «*Francis turbine draft tube modelling for prediction of pressure fluctuations on prototype*», Journal of Physics: Conference Series, vol. 656(1)

HYPERBOLE
ERC/FP7-ENERGY-2013-1-Grant 608532
HYdropower plants PERformance and flexiBle Operation towards Lean integration of new renewable Energies

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Understanding the unstable off-design operation of Francis turbines for large scale NRE integration

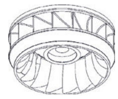
A. Favrel, K. Yamamoto, A. Müller, C. Landry and F. Avellan

Context

Unsteady power output from renewable energies

Electrical grid is exposed to large fluctuations

Balancing by off-design operation of hydropower plants



High swirl and unstable cavitation flows

Research Project

The HYPERBOLE research project (ERC/FP7- ENERGY-2013-1-Grant 608532), consisting of leading European universities and turbine manufacturers, aims at making a decisive contribution towards the smooth integration of NRE by enabling the safe extension of Francis turbines operating range.

Objectives:

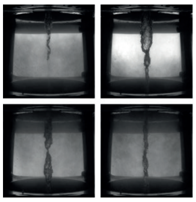
- Reach a profound understanding of the underlying physical mechanisms leading to an unstable behaviour of hydropower unit operating in off-design conditions
- Enhance the accuracy of existing models for a comprehensive simulation of hydroelectric power plants over their whole operating range.

Flow instabilities in off-design conditions

Francis turbine units operating in off-design conditions experiences the development of flow instabilities, inducing cavitation and periodical / stochastic pressure pulsations in the hydraulic system:

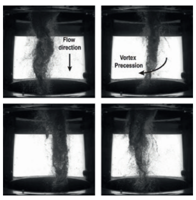
FULL LOAD:

Self-oscillation of an axisymmetric cavitation vortex rope in the draft tube inducing pressure, torque and power pulsations



PART LOAD:

Precession of a cavitation vortex rope in the draft tube acting as a pressure excitation source with risk of resonance

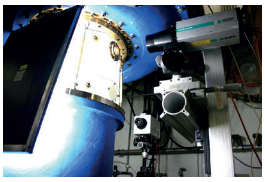


DEEP PART LOAD:

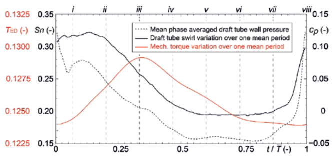
Cavitation vortices in the inter-blade channels (inter-blade vortices) with unknown draft tube flow interaction and erosive potential

Investigative approach & Results

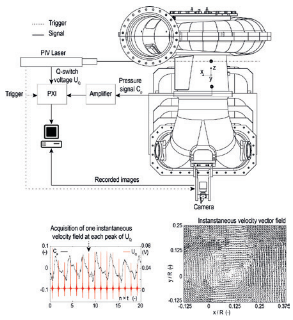
2D-LDV to determine the flow velocity fluctuations and identify the unstable fluid-structure interaction mechanisms at **full load**



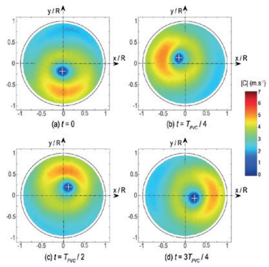
Variation of the flow swirl, pressure and torque over one instability period



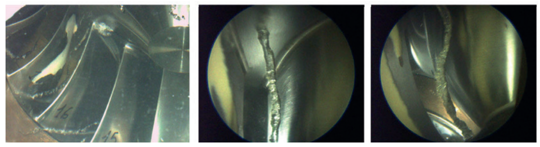
2D-PIV to identify the influence of the flow discharge on the vortex structure and parameters at **part load**



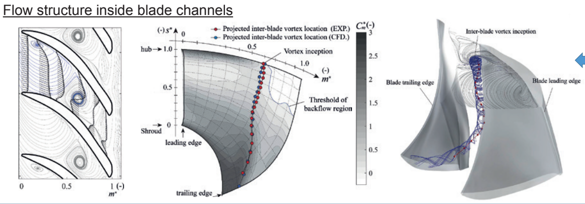
Evolution of the flow velocity field over one precession period



Visualizations with instrumented guide vanes & **CFD** simulation to capture the inter-blade vortices at **deep part load**



Flow structure inside blade channels



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[1] Müller A. et al. (2017), "*Fluid–structure interaction mechanisms leading to dangerous power swings in Francis turbines at full load*", Journal of Fluids and Structures, vol. 69, 56-71.

[2] Favrel A. et al. (2015), "*Study of the vortex-induced pressure excitation source in a Francis turbine draft tube by particle image velocimetry*", Experiments in Fluids, 56(12)

[3] Yamamoto K. et al. (2017), "*Experimental evidence of inter-blade cavitation vortex development in Francis turbines at deep part load condition*", Experiments in Fluids, Article in press

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Performance assessment of a new kinetic turbine prototype

A. Gaspoz[1], S. Richard[1], V. Hasmatuchi[1], N. Brunner[2], C. Münch-Alligné[1]
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Objectives of this "pilot & demonstrator" project

- Design and construction of a first prototype of isokinetic turbine for artificial channels with a power of 1 kW
- Evaluation of its hydraulic performances in the tailrace canal of the Lavey run-of-river powerplant (Rhône river)
- Validation of the numerical simulation results
- Preparation of an industrialization phase to exploit this energetic potential in Switzerland and abroad

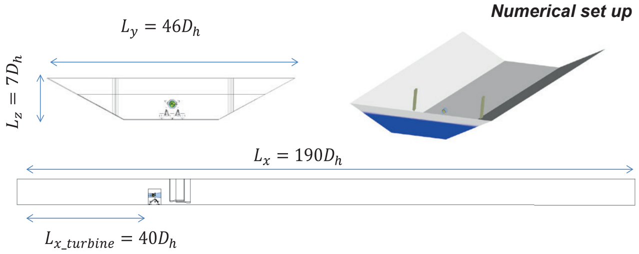
Pilot site

The pilot site to assess the performance of the first prototype is the tailrace channel of the run-of-the-river Lavey Hydropower plant in Switzerland. At the end of 2016, the open-air platform and the turbine have been installed in the tailrace channel.

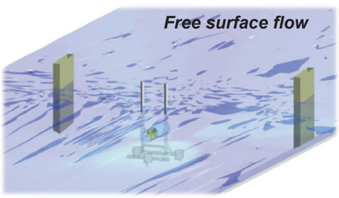
Numerical investigations

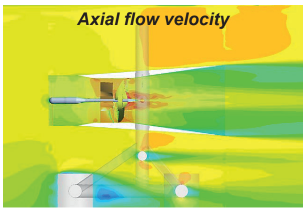
Unsteady multiphase homogeneous flow numerical simulations of the turbine in the tailrace channel of Lavey have been performed using the ANSYS CFX software. The incompressible Reynolds Averaged Navier–Stokes equations are solved using a finite volume approach. The set of equations is closed-formed and solved using a two-equation turbulence model: the Shear Stress Transport (SST) model. A hybrid mesh of 13 Millions of nodes is used.

Numerical set up

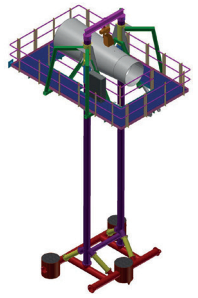


The numerical results have shown that the turbine has no impact on the available head of the Lavey powerplant. Moreover the Venturi effect of the duct and the specific design for the runner induce a strong acceleration of the flow inside the machine, as expected [1].





Experimental investigation



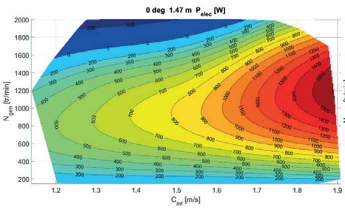
To measure the performance of the kinetic turbine on the pilot site, a specific instrumentation has been set up [2]:

- Acquisition/control system
- River boat equipped with an ADCP system
- Electrical multimeter
- Onboard instrumentation

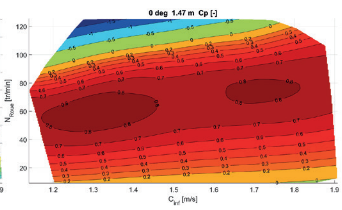
Performance assessment

The turbine performance is obtained by measuring the produced electrical power compared to the available hydraulic power [3]. The objective of the project to reach 1kW with the turbine has been largely outshined with a maximal electrical power measured of 1.5 kW.

Electrical power production

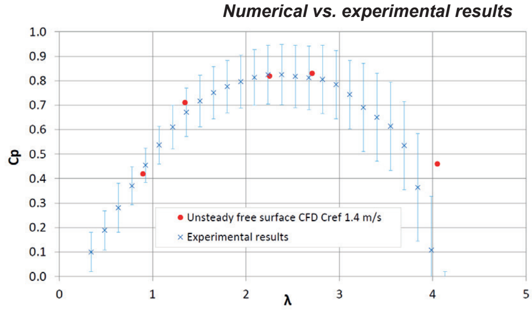


Power coefficient



The numerical and experimental performances have been compared and a very good agreement is observed:

Numerical vs. experimental results



Conclusions and perspectives

These investigations have shown that:

- The objective of the project to produce 1kW with a new prototype of a kinetic turbine has been reached.
- Unsteady two phase flow numerical simulations allow to predict performance fairly accurately at BEP.
- The next step is the installation of a farm of kinetic turbines to investigate the influence of the machines between each other.

Acknowledgements

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the ark STAHLEINBAU SiL SERVICES INDUSTRIELS LAUSANNE SWISS VIT

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[1] C. Münch, A. Gaspoz, S. Richard, V. Hasmatuchi, N. Brunner, 2017, "New prototype of a kinetic turbine for artificial channels" Simhydro Conference, Nice, 14-16 June.

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[3] S. Richard, A. Gaspoz, V. Hasmatuchi, N. Brunner, S. Chevailler, C. Münch-Alligné, 2017, "Development of an experimental protocol to assess the new kinetic turbine performance", Annual conference, SCCER SoE, Zurich.

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Empirical models for Francis turbine performance estimation

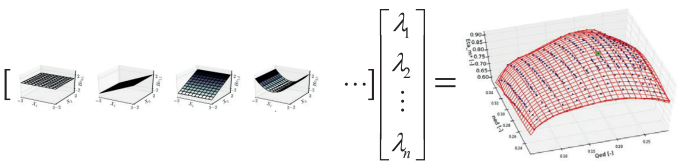
J. Gomes, L. Andolfatto, F. Avellan

Motivation

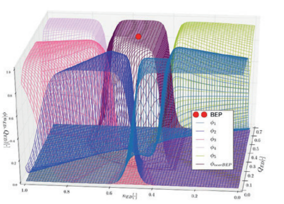
- The **Energy Strategy 2050**: more energy generation from renewable sources;
- In Switzerland, **many hydropower plants can be upgraded or rehabilitated** therefore generating more power with the same amount of water **[1]**;
- Many feasibility studies, such as those for upgrading or rehabilitating the power plants, take the turbine's efficiency as a constant and don't check off-design or transient conditions.
- Being able to properly evaluate these other conditions and optimize the project from the very beginning is the added-value of this research work

Methods

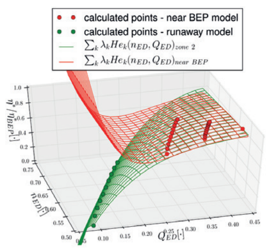
- Representing the efficiency as a set of parameters **[2]**



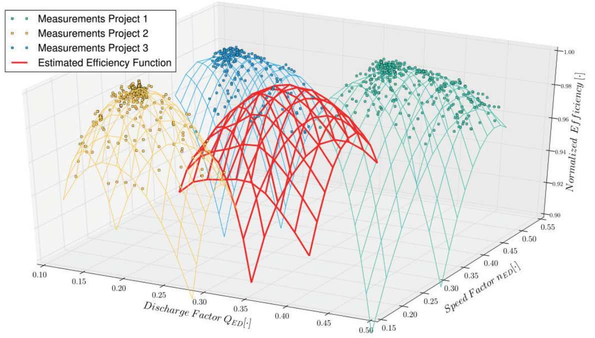
- For better precision, more complex efficiency surfaces may be achieved through a combination of low order polynomials and weighting functions



$$\eta(Q_{ED}, n_{ED}) = \sum_{i=1}^{6} \phi_i \sum_j \lambda_{i,j} He_j\left(g_i\left(Q_{ED}, n_{ED}\right)\right)$$



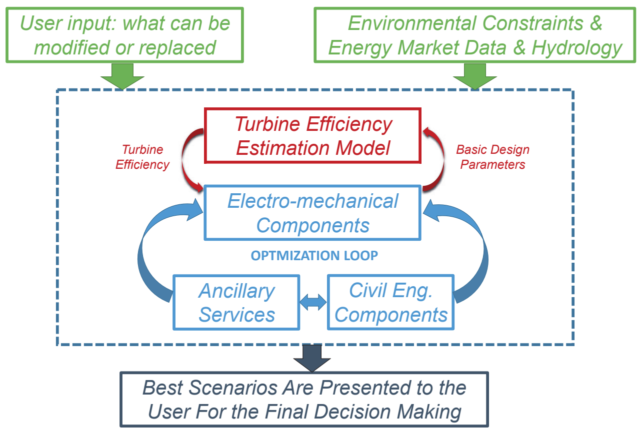
- Available test data used to train the empirical models



RENOV Hydro

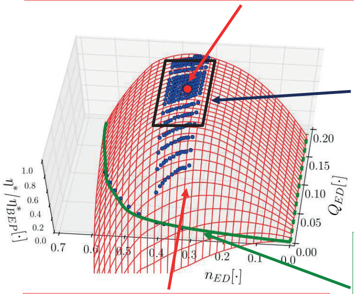
The RenovHydro CTI project no. 19343.1 PFIW-IW will create a **decision making assistant for hydropower project potential evaluation and optimization**.

- 3 years project, started in Dec. 2016;
- Empirical models for the turbine efficiency estimation is inside the Work Package 1 (Francis, Pelton and Kaplan turbine types);
- Partners:

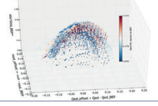


Generating efficiency estimation curves in 4 steps:

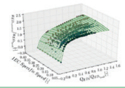
1-Peak Efficiency Estimation: based on an adaptation of a model developed by Gordon, J.L. [3], the peak effiency η_{BEP} is estimated according to the turbine's year of commissioning, size and specific speed:



2- Typical operation zone: empirical model based on measurements performed at LMH-EPFL



3-Runaway curve: empirical model. Curves are adjusted according to the turbine's specific speed



4- Transition zones: low order polynomials combined with weighting functions make the transition between runaway and operating zone values.

Conclusion

By means of a combination of empirical models trained with data obtained from efficiency measurements of Francis turbines through a spam of almost a hundred years [3], a methodology has been developed aimed to predict the performance of Francis turbines.

Inside the RenovHydro Project, an optimization loop that searches for the best combination of electro-mechanical, civil engineering components and ancillary services will make use of these turbine efficiency predictions to define the most suitable design parameters of the future Francis turbine.

A very good agreement has been observed between predictions and measurements, both for steady, typical operating conditions and for simulations of transient conditions such as an emergency shutdown.

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[2] – Andolfatto, L. et al., 2015. - *Analytical Hill Chart Towards the Maximisation of Energy Recovery in Water Utility Networks with Counter-Rotating Runners Micro-Turbine*. The Hague, 36th IAHR World Congress 2015
[3] – Gordon, J. L., 2001. - *Hydraulic Turbine Efficiency*. Canadian Journal of Civil Engineering, 28(2), pp. 238-253

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Impact of polymers in well cementing for geothermal wells

*M. Palacios, R. K. Mishra, D. Sanz-Pont, R. J. Flatt**

1. Introduction

Backfilling with cementitious material is essential for mechanical stability of deep wells. However, with increasing depth temperature rises involving many technological challenges such as poor rheological properties and quick setting of cement slurries. On site, a combination of different chemical admixtures including dispersants, set retarders and accelerators are normally used although a loss of performance is often found.

In the Group of Physical Chemistry of Building Materials, in the frame of WP3 Task 3.1 “Geo-energy technologies”, we investigate the use of specific comb-copolymer superplasticizers to control cement hydration kinetics and rheological properties of cement slurries at the extreme conditions encountered in geothermal well. This will be done using an experimental and molecular modeling approach.

2. Methods

- **Isothermal calorimetry** to study the impact of polymer structure and dosage on cement reaction kinetics with the temperature.
- **Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES)** and **Dynamic Light Scattering (DLS)** to analyze cement pore solutions.
- **High-end rheometer** to investigate the rheological properties of the superplasticized retarded mixes.
- **MD simulation** to understand the interaction between organic admixtures and the chemical species present in solution.

3. Highlights of the project

It has been demonstrated for first time that cement hydration can be delayed at high temperatures by specific dosages and structures of comb-copolymer superplasticizers (**Figure 1**).

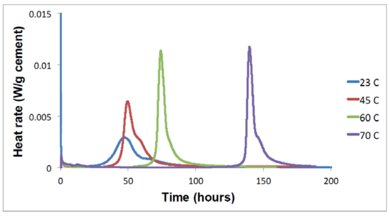


Figure 1. Calorimetry curves at different temperatures of cement pastes in presence of a specific comb-copolymer

The analysis of the chemical composition of the cement pore solution using ICP-OES method[1] has proved a dramatic increase in the concentrations of Si, Al, Fe and Mg, in admixed cement pastes hydrated at 23 °C (**Figure 2**). The formation of polymer aggregates involving intramolecular complexes between polymers and multivalent cations could explain the increase of these elements.

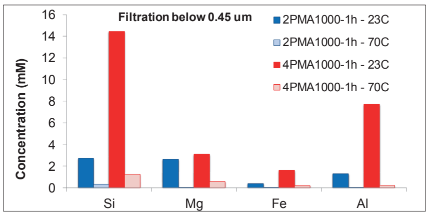
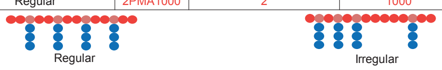


Figure 2. Analysis of pore solutions of admixed pastes by ICP-OES.

Distribution of Side Chains	Polymer	Carboxylate/ether (C/E)	Side chain (g/mol)
Irregular	4PMA1000	4	1000
Regular	2PMA1000	2	1000



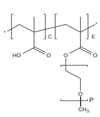


Figure 3. Structural details of comb-copolymer PCE superplasticizers.

The mechanisms behind molecular interactions between tricalcium silicate (main phase of cement) and aluminate ions has been firstly studied by molecular dynamics (MD) simulations using all-atom accurate force field models (**Figure 4**). Upon progress of hydration and at higher pH values, the binding strength of aluminates to the hydroxylated C_3S decreases so that its passivating effect, and retardation, are reduced (**Table 1**).[2] Furthermore, the interactions between the aluminate ions and PCE comb-copolymers have been investigated (**Figure 5**).

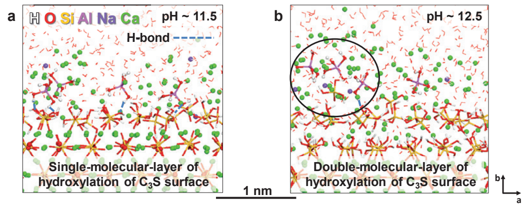


Figure 4. Interactions of aluminate ions with the hydroxylated C_3S surface. (a) Interactions of aluminate ions with the initially hydrated C_3S surface at pH ~ 11.5 involve strong bonding to calcium ions on the surface as well as interfacial hydrogen bonds (Al–OH···O⁻–Si and Al–OH···OH–Si). (b) Interactions of aluminate ions with the C_3S surface at pH ~12.5 are weaker. Dissolution of silicate ions and formation of ionic complexes between aluminate and calcium ions, aluminate ions and silicate ions (circular highlight) can be seen.

Table 1. Adsorption energy of $NaAl(OH)_4$ on the hydroxylated C_3S surface under ambient conditions for different hydration depth and added NaOH.

Type of C_3S surface	Adsorption energy (kcal/mol/molecule)	pH	Amount of hydration
Hyd.C_3S ($SiO(OH)_3^{1-}$)	–24 ± 6	11.5	Single molecular layer
Hyd.C_3S ($SiO(OH)_3^{1-}$)	–6 ± 3	12.5	Double molecular layer
Hyd.C_3S ($SiO(OH)_3^{1-}$) + NaOH	0	13.4	Single molecular layer

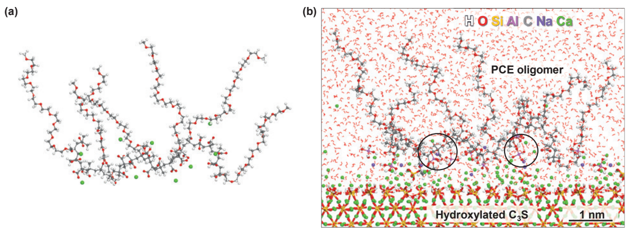


Figure 5. (a) Structure of PCE with six side chains.(b) MD snapshot of interaction between aluminate ions and polycarboxylate ether (PCE) admixture on the hyd. C_3S surface. Complex formations happen between carboxylate group and aluminate ions (circular highlight).

4. Ongoing research

The following studies will give new insights into the design of more robust cement grouts:

- Role of complex formation between polymer and multivalent (Al, Mg and Fe) cations
- Influence of the temperature on the adsorption of the polymer.
- Impact of PCE admixtures in presence of Mg and Fe ions

References

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Extension of Francis Turbine Operating Conditions by Controlling the Part Load Vortex Rope

Pasche S., Gallaire F., Avellan F.

Problematic

This project consists of applying the latest flow control theories to an important issue arising in hydraulic turbines: the development of a cavitation vortex rope at part load conditions in Francis turbines.

With the future massive introduction of renewable energy in the distribution systems, the operation of Francis turbines at off-design conditions, such as the part load regime, is thought to be one of the main solutions to mitigate large power fluctuations of the grid.

An intense cavitation rope is however known to appear in these conditions, which produces large pressure fluctuations at a well-defined frequency, with the associated hazards induced by the risks of operating instability and fatigue and resonance of the mechanical structures.

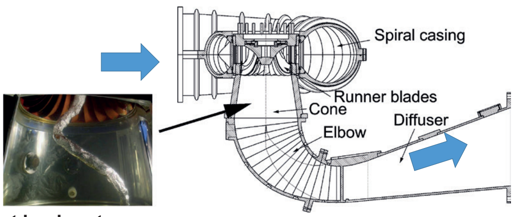
Objectives

Control the part load vortex rope to enable the extension of Francis turbine operating conditions and to further enhance the power generation flexibility of these generating units

Methods

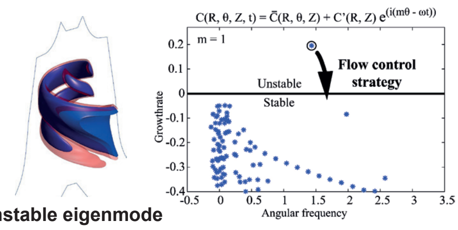
Since the part load vortex rope is identified as an unstable eigenmode, a flow control strategy aiming at stabilizing this spatially developing mode is applied to obtain an optimal volume force controlling the part load vortex rope.

Francis turbine



Part load vortex rope

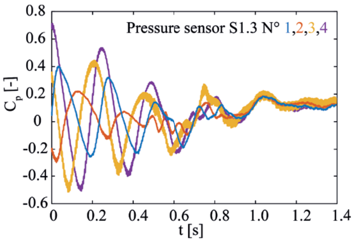
Part load vortex rope eigenvalue spectrum and flow control strategy

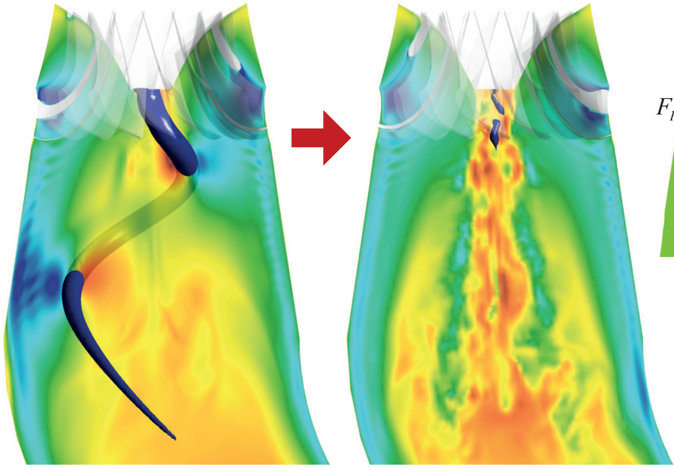


Unstable eigenmode

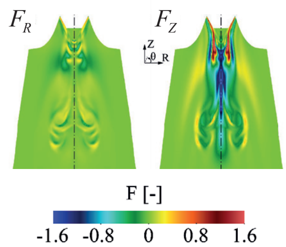
Results

Transient wall pressure signal of the part load vortex rope control





Optimal volume force



Conclusion

A new fluid flow control strategy aiming at stabilizing the development of self-sustained instabilities is applied to the Francis turbine vortex flow operating at part load conditions. This approach has led to the determination of the amplitude and the location of an optimal volume force, which successfully controls the part load vortex rope and can be, in a future work, realized by a passive control appendage. The enhancement of operation flexibility of Francis turbine is therefore numerically achieved in this project, which sheds a new light in the potential development of hydraulic turbines in mitigating electric power fluctuations.

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Development of an experimental protocol to assess the new kinetic turbine performance

S. Richard[1], A. Gaspoz[1], V. Hasmatuchi[1], N. Brunner[2], S. Chevailler[1], C. Münch-Alligné[1]
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[2]Stahleinbau Gmbh, Talstrasse 30, CH-3922 Stalden, Switzerland

Context

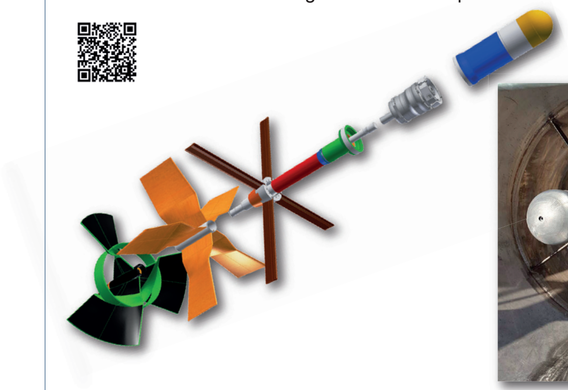
- The first prototype of an isokinetic turbine for artificial channels with a power of 1 kW has been designed, optimised and manufactured [1].
- Its hydraulic performances have to be measured directly on a pilot site represented by the tailrace canal of the Lavey run-of-river powerplant (Rhône river) [2-3].

Objective:

- Development of an experimental protocol to assess the performance characteristics of the machine on the whole operating range using the available instrumentation.

Electro-mechanical concept

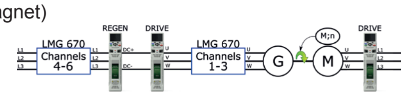
- Sealed bulb housing including the variable speed generator, the encoder, the speed multiplier and the mechanical coupling
- 1kW compact permanent magnet synchronous generator
- Coaxial gear speed multiplier with a factor of 1:16
- Mechanical shaft sealing: resistant to suspended sediment conditions



Performance tests of the generator

Main characteristics:

- Phase TK142-100-041-G-R0-pa synchronous machine
- 12 poles (permanent magnet)
- Water cooled
- Rated power: 2.39 kW
- Rated current: 6 A
- Rated/maximum speed: 1'000/2'000 rpm



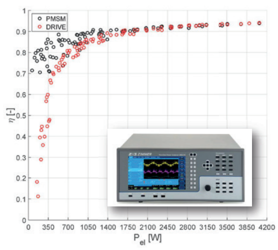
Components of the testing bench:

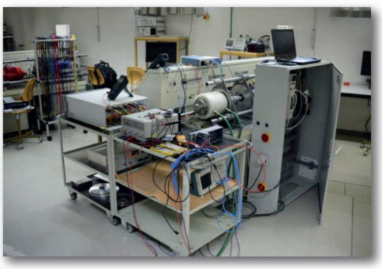
- Testing generator
- Torquemeter & encoder
- Entrainment motor unimotor fm 142U2E300
- Emerson M700 frequency converters

Instrumentation:

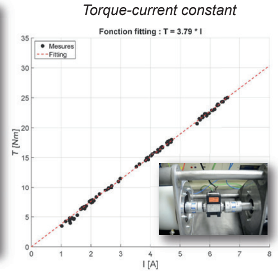
- Magtrol TMB 208 torquemeter
- Heidenhein ECN 1325 encoder
- Zimmer LMG 670 precision multimeter

Electrical performances





Torque-current constant



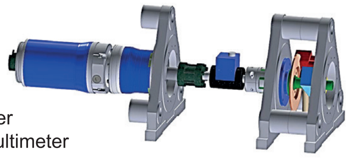
Performance tests of the gear box

Experimental methodology:

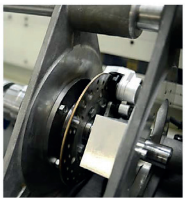
- Generator-gear box tested together
- Specific system allowing up to 260 N.m manual breaking torque
- Performance measurements based on synchronized dynamic acquisition of sensors signals

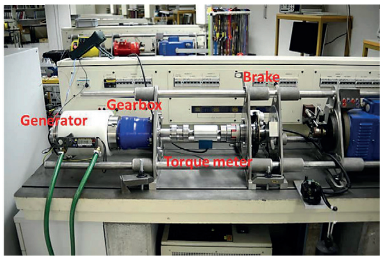
Instrumentation:

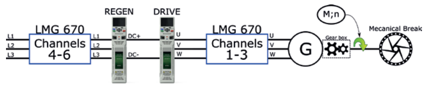
- NCTE 3000 torquemeter
- Heidenhein ECN 1325 encoder
- Zimmer LMG670 precision multimeter
- NI cDAQ-7124 signals digitizer



Brake – manual charging



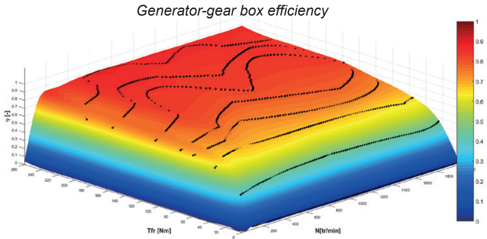




Main result:

- Dependency between the mechanical-to-electrical efficiency of the assembly generator-gear box and the measurements of the generator true-rms values of the current and the speed
- This methodology allows retrieving the hydraulic-to-mechanical efficiency of the turbine runner without torquemeter

Generator-gear box efficiency



Conclusions

- Performances of the electrical generator successfully measured
- Performances of the assembly between the electrical generator and of the gear box successfully retrieved using the dynamic method
- The established experimental protocol enables the performance measurements of the new isokinetic turbine prototype directly in the tailrace canal of the Lavey powerplant

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Expected Corrosion Issues in Geothermal Power Plants in Switzerland

*A. Vallejo-Vitaller, U. Angst, B. Elsener **

1. Introduction

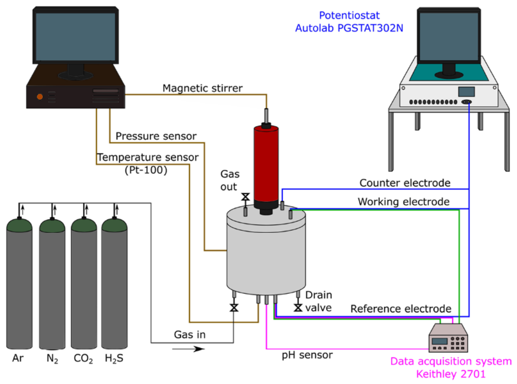
In Switzerland, the co-generation of electric power and heat from deep geothermal resources is gaining further attention. However, the expertise in operational issues and the knowledge of chemical properties of deep geothermal fluids (at depths of 4-5 km) is still limited. [1]

In this context, one of the main technical problems for the reliable and long-term operation of binary power plants is corrosion. Metallic materials, such as low-alloyed steels, are mainly subject to uniform corrosion, pitting corrosion, or stress corrosion cracking. The electrochemical reactions between the material and the environment lead to different types of corrosion products.

Therefore, the goal of this project is to contribute to a more detailed understanding of the corrosion mechanisms and the characterization of various metallic materials under various scenarios in Switzerland.

2. Experimental methods

An experimental setup consisting of a high temperature-high pressure test vessel has been used for the tests. The autoclave is heated from room temperature up to 200°C and subsequently cooled down. The heating and cooling cycles usually take ca. 15h.



Electrochemical techniques

The open circuit potential (OCP) is measured continuously during the tests with a multimeter Keithley 2701. Linear polarization resistance (LPR) measurements are performed at given temperatures (usually at 80, 120, 160, and 200°C) with a potentiostat Autolab PGSTAT302N. The corrosion rate is then calculated as given by the Faraday's law:

$$Corrosion\ rate = \frac{M \cdot i_{corr}}{z \cdot F \cdot \rho}$$

M : molecular weight (g/mol)
i_{corr} : corrosion current density (A/cm^2)
z : valency of metal ion
F : Faraday's constant (96485 As/mol)
ρ : density of metal (g/cm^3)

Materials

The steel grade L80 Type 1 (0.25%C, 1.02%Mn, 0.45%Cr) is a typical low-alloyed steel used for the casing of wells and produced according to the API specification (American Petroleum Institute).

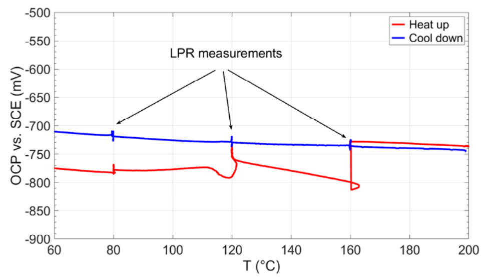
Synthetic fluids

Aqueous solutions were deaerated with N_2 gas for ca. 1-2h.

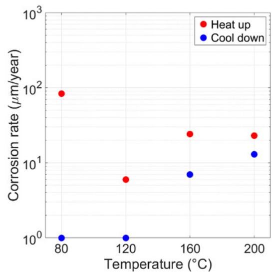
pH	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-
8.4-8.6	10.0	0.0	282.0	0.0	375.0	300.0	0.0

3. Results

Open Circuit Potential (OCP) evolution



Linear Polarization Resistance (LPR) measurements

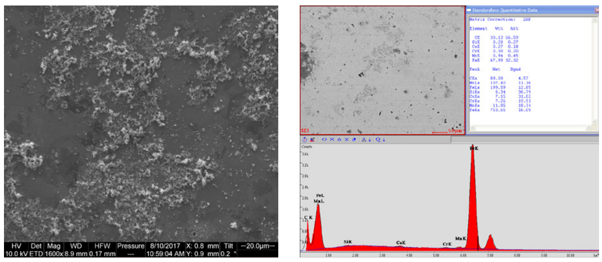


- Corrosion rates are lower during the cooling cycle
- Average corrosion rate is approx. 20µm/year

pH value

The pH value remains stable (8.2 ± 0.3 units) over the whole range of testing temperatures (20-200°C).

SEM and EDX analysis after test



4. Conclusions and future work

- The OCP does not vary significantly with temperature (-750mV vs. SCE). According to the Pourbaix diagram of iron, the obtained value suggests that this element is in the oxidation state Fe^{2+}.
- Furthermore, the LPR measurements show that there is no dependency of the corrosion rate on temperature.
- From the SEM and EDX analysis, it can be seen that different oxides adhere to the metal surface (mostly carbonate components).
- Although the corrosion rate slightly changes with temperature (approx. 20µm/year), the corrosion behaviour of the material over longer time spans is still unknown. Further investigations on the protection provided by the corrosion products to the base metal are necessary.

5. References

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