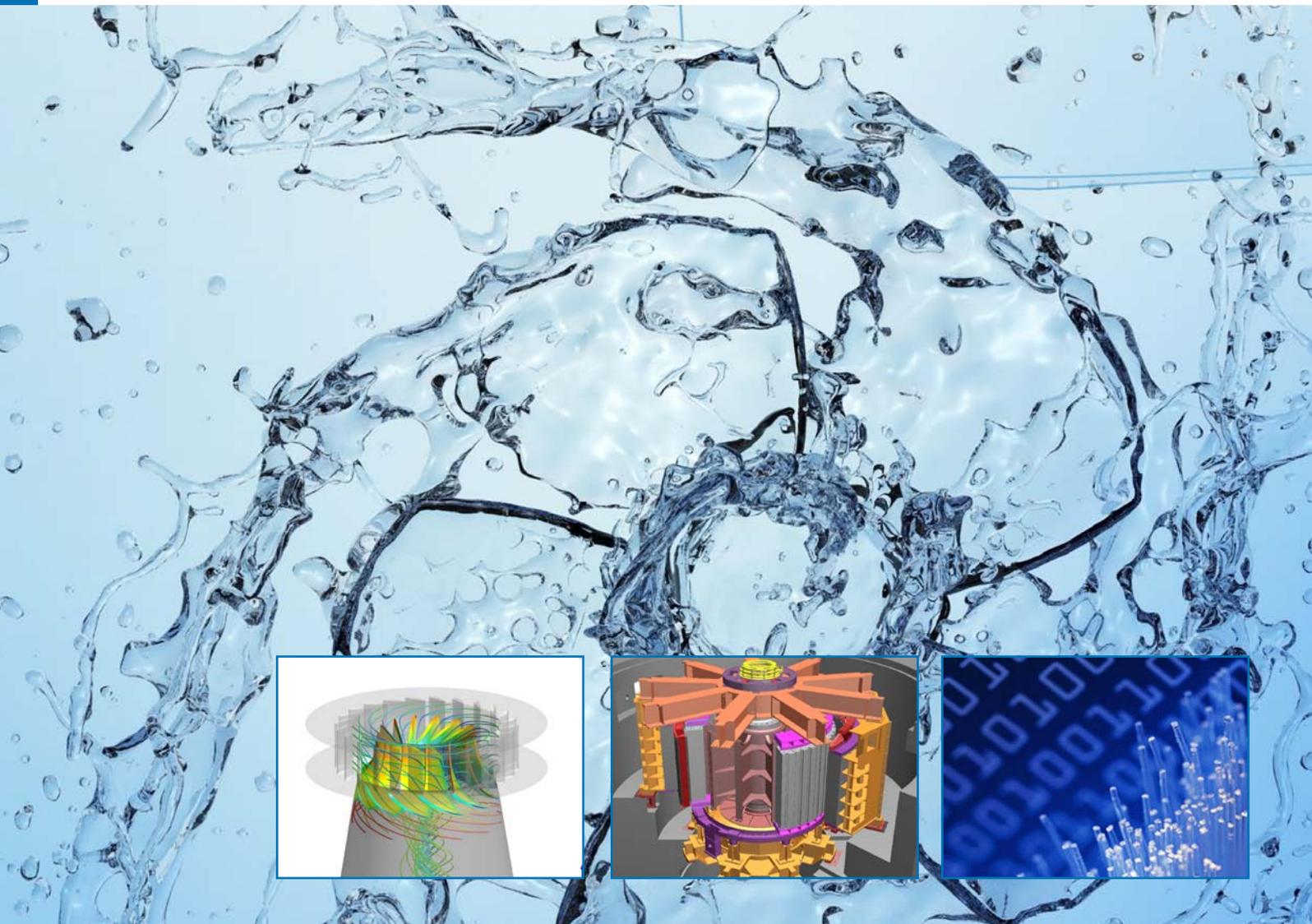
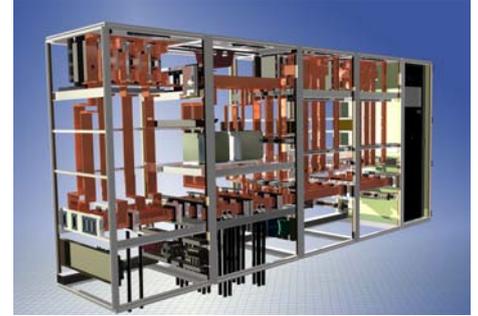
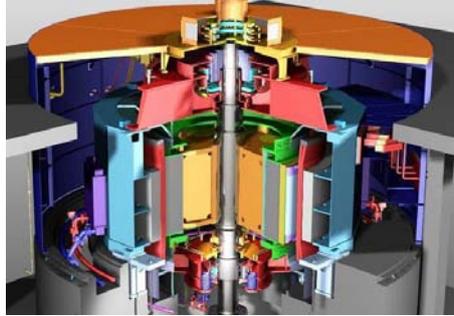
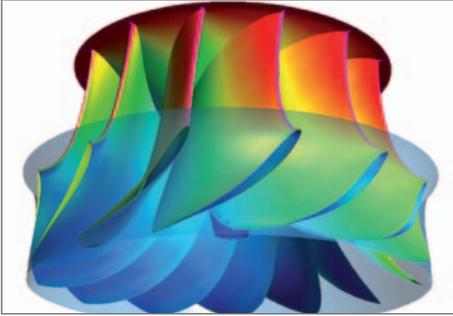


Research and development



ANDRITZ HYDRO

Leader in technology over many generations



ANDRITZ HYDRO is a global supplier of electromechanical equipment and services (“From water to wire”) for hydropower plants and one of the global market leaders for hydraulic power generation. The company’s long history has seen many reputed enterprises as well as excellent researchers and developers in hydropower (Escher Wyss, Kaplan, Bouvier, Pelton Waterwheel, ELIN, GE, etc.). Today, the technology leader’s role is still a strong motivation for young engineers. ANDRITZ HYDRO’s research and development (R&D) engineers successfully combine their vision of the future with the experience of previous generations of researchers.

ANDRITZ HYDRO develops both, customized designs and standardized, cost-efficient solutions for the most different

requirements of large new power stations (Rio Madeira, Brazil – 90 bulb-type turbines) as well as for small hydropower plants. For the renovation, modernization, and expansion of existing large plants (e.g. Simon Bolivar II, Venezuela - 770 MW) as well as of smaller units, ANDRITZ HYDRO supplies specialized solutions, optimized in accordance with the 3-phase concept (Diagnosis – Analysis – Therapy). Primarily for smaller renovation projects, a large number of these turbines are designed entirely on computers without any model tests.

ANDRITZ HYDRO R&D is a leader and pioneer in the field of automation, where innovation cycles are very short. R&D for hydro generators comprises both, state-of-the-art computation methods for electrical, me-

chanical and thermodynamic conditions, as well as experimental investigations in the fields of insulation and bearing technologies. As regards turbo generators, there is a long-term R&D cooperation with one of the leading providers in the world market. R&D is embedded in a global technological structure and uses the synergies from a decentralized and multi-cultural structure in an optimum way. Every location has a clearly defined research and development focus. The direct involvement of R&D staff in project development, preparation of tenders, and project execution is a crucial factor in economic success.

Customers and consulting engineers have direct access to R&D know-how, while current market feedback flows directly in future developments.

Highlights

- Biudron, Switzerland (H= 1,869 m, P= 423 MW): world record Pelton turbine
- Goldisthal, Germany (P= 380 MVA): large pump turbines; first large variable-speed motor generators outside of Japan
- Häusling, Austria (H= 734 m, P= 180 MW): world record Francis turbine
- Three Gorges, China (P= 710 MW), Simon Bolivar II, Venezuela (P= 770 MW): high-capacity Francis turbines
- Bulb generators, Jirau, Brazil (P= 83 MVA): large bulb units; largest number of references for large bulb turbines with low head

Research and development

Efficiency increase, focus on customer benefit

Continuously increasing demands by hydropower customers emphasize the significance of R&D in the continuous optimization of products and services. ANDRITZ HYDRO R&D comprises the fields of turbine design, generator design, and automation, including electrical systems.

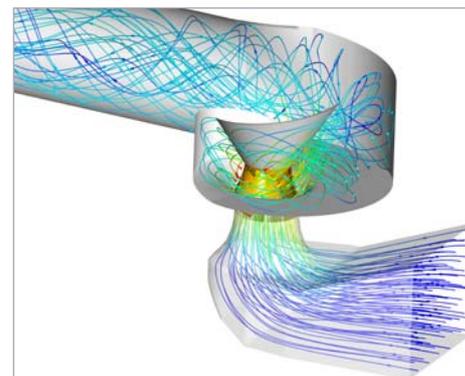
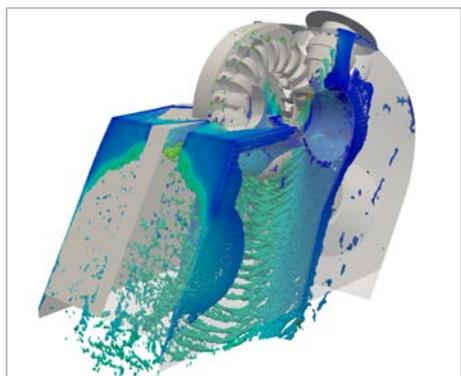
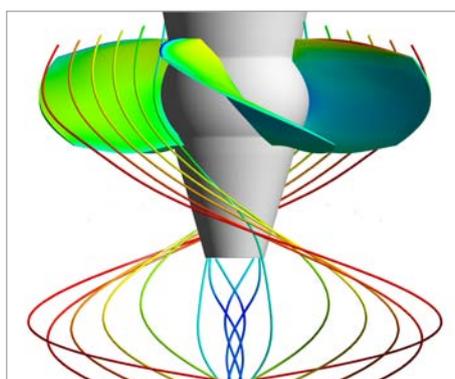
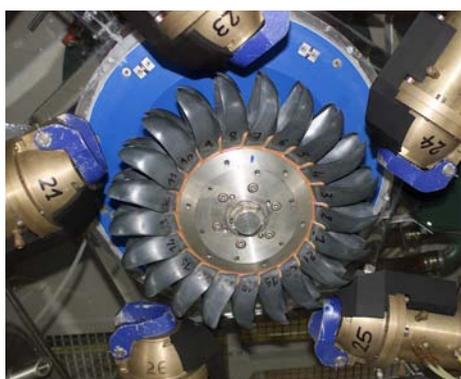
Today, efficiency, flexibility, and reliability over an extended lifetime are the major challenges of the market. In order to meet global requirements, research activities by

ANDRITZ HYDRO focus on the holistic improvement of hydraulic and electrical capacities.

The main tools for R&D are numerical simulation methods as well as experimental measurements in the laboratory and on site. State-of-the-art equipment, highly-precise measuring instruments as well as the latest simulation technologies, and powerful software are the best recipe for successful development. To manage future

challenges ANDRITZ HYDRO focuses its activities on new products, product properties, and manufacturing methods. This is based on active research in the fields of material engineering, fluid and structural mechanics, electrical design, and electronics. The findings of basic research are used immediately in product development.

In all our efforts, the benefit for our customers has priority.



Turbines and pumps

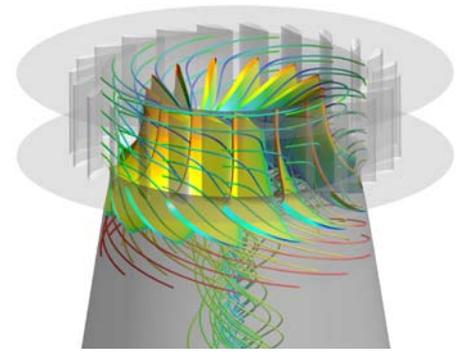
Hydraulic turbine design requires an understanding of complex physical phenomena. Numerical flow simulation (Computational Fluid Dynamics – CFD) and stress analysis (Finite Element Analysis – FEA) deliver important insights into flow and mechanical structural properties. The quality of analysis methods is a direct result of the underlying mathematical models. Many time-related flow phenomena and special issues of fluid-structure interaction or system stability cannot yet be modelled with sufficient precision using today's computation methods. For this reason, ANDRITZ HYDRO is constantly active in the development of modelling and analysis methods.

Design procedure

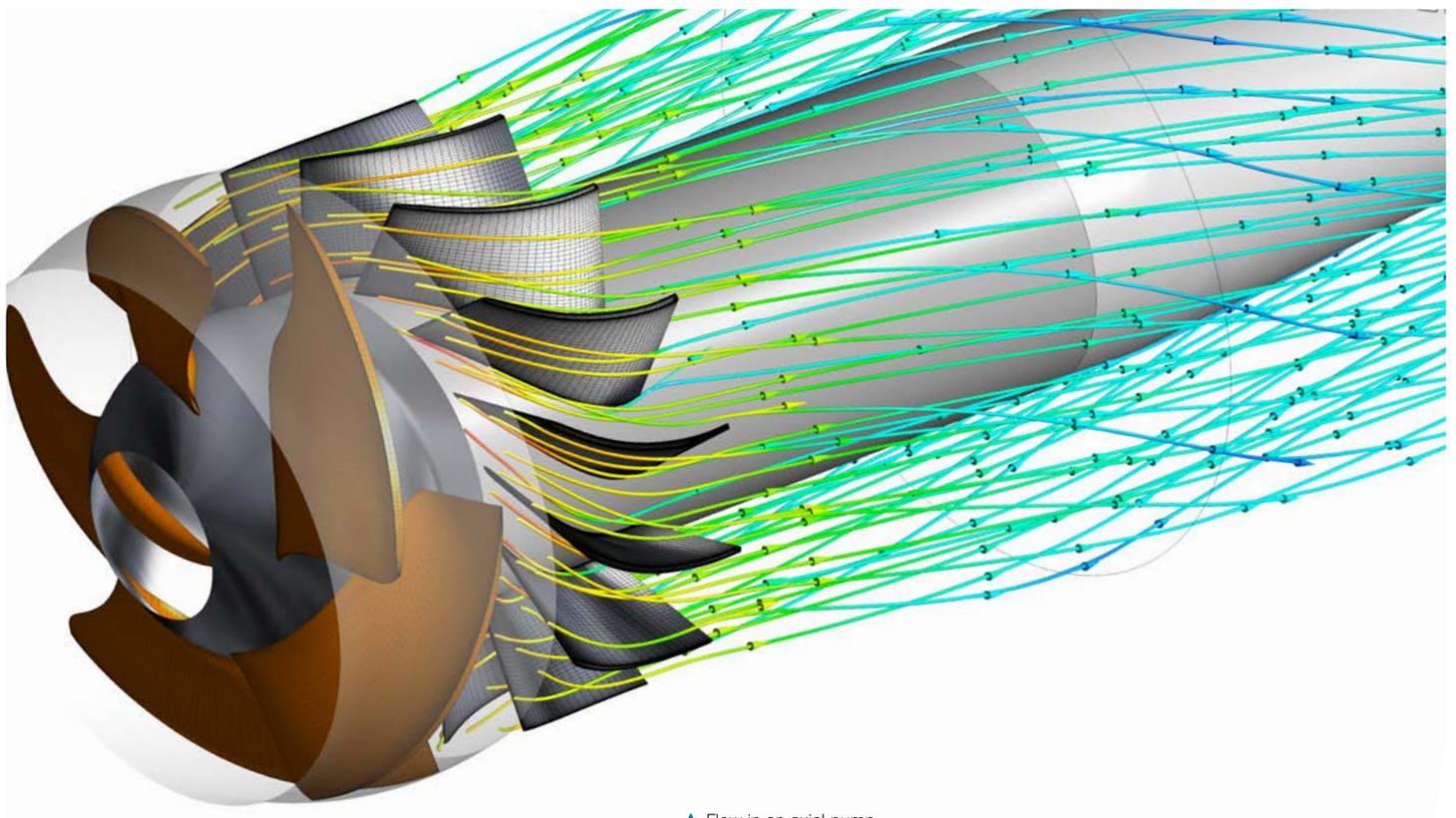
CFD is currently the standard method used by engineers in designing hydraulic turbines. In addition to CFD simulation and model tests engineers use the comprehensive experience gained with previously constructed turbines and plants. In the first optimization step the rotating runner is analyzed and pre-dimensioned by applying a rapid method that does not consider friction (3D Euler). In the second step the runner is optimized in combination with fixed components by applying the 3D-Navier-Stokes method, which takes account of viscosity effects and turbulences in the flow. Depending on the respective project another optimization step can be implemented on the test stand. The stress analysis is performed in parallel to the hydraulic design process so that the profile is optimized with regard to hydraulic performance and lifetime.

Dynamic behavior

Vibrations, pressure oscillations and performance fluctuations may result in significant problems during operation or in a reduced components lifetime. In many cases flow phenomena are the cause of vibrations. ANDRITZ HYDRO performs numerical analyses in order to detect and prevent vibrations and resonance in the early stages of design work .



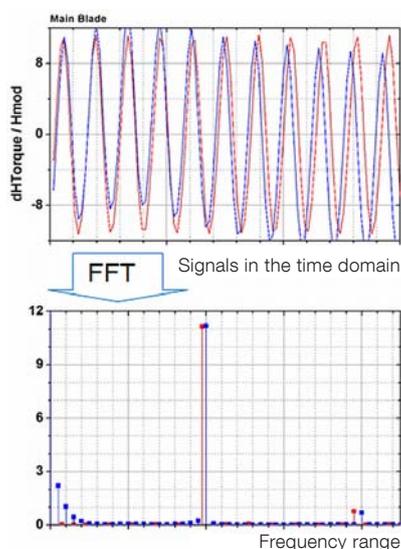
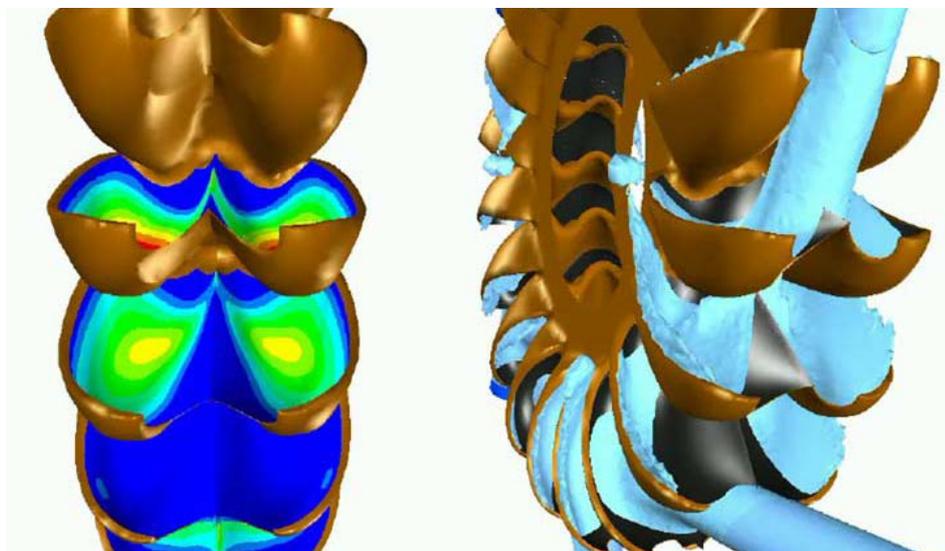
▲ Visualization of flow in a Francis runner



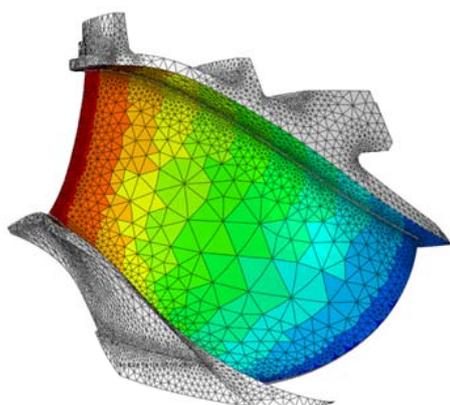
▲ Flow in an axial pump

Jet-bucket interaction

In Pelton turbines the jet quality has a significant effect on the turbine efficiency. The flow in Pelton buckets is highly complex, time-related, in two-phases with a free surface. By means of intensive research, measurements, and CFD verifications the Pelton jet CFD computations could be predicted with a high degree of accuracy. CFD simulations of the Pelton bucket flow not only provide values regarding hydraulic efficiency, but also form the basis of the stress analysis and the analysis of potential resonance problems.



▲ Rotor-stator interaction: Momentum fluctuations on the runner blades



▲ Stress analysis of a Francis runner

Time-related interaction between rotor and stator

The dynamic stress on Francis and pump turbine runners results from the interaction between the rotating pressure field in the runner and the stationary pressure field in the guide vanes.

Due to customer requests for light-weight machines with higher specific capacities, dynamic stress has become a significant aspect of design. Its precise prediction requires highly sophisticated CFD simulations, which provide the limits for the stress analysis.

The stress analysis of a Francis runner provides both, static and dynamic stress values. In Kaplan turbines rotor-stator interaction is less important due to the larger distances between the guide vane and the runner blades. Nevertheless, vibration may occur and cause problems during operation. Thanks to the recently developed analysis tools, ANDRITZ HYDRO is now capable of analyzing and excluding this risk as early as the design phase.

Francis draft tube rope

In Francis and pump turbines the draft tube flow under full and partial load may become unstable as a result of pressure oscillation if a rotation vortex rope develops. The occurrence of excessive pressure oscillation and performance fluctuations could make the safe operation of a hydropower station impossible. The prediction reliability for swirling flows in the draft tube and for the cavitating vortex-rope has improved significantly after years of measurements and refining of CFD simulation.



▲ Francis draft tube rope

Turbine and pump test stands

Hydraulic development is based on numerical flow simulation and model tests. In the hydraulic laboratories of ANDRITZ HYDRO turbines are optimized and tested for preparation of tenders and contracts.

In every stage of a project hydraulic tests are important for the further development and optimization of the hydraulic equipment and its components.

Design properties intended to meet future customer demands are investigated and tested using state-of-the-art laboratory and measurement technology.

Experiments and numerical flow simulation are the basis of our research activities. Numerical flow simulation is a highly developed tool for obtaining an insight into flow behavior.

Some phenomena, such as pressure oscillation, two-phase flow with cavitation, vortex-rope or operation under runaway conditions (load rejection) can only be examined with the required accuracy on the test stand. In particular, the feedback to the numerical flow simulation contributes towards improving its accuracy and verifying CFD methods for new applications.

The hydraulic laboratories of ANDRITZ HYDRO are suitable for testing all types of hydraulic turbines and pumps and also performing acceptance tests for customers.

The engineers working in the laboratories improve their measurement techniques continuously and develop new measuring methods.

We attach great importance to achieving utmost measuring accuracy using advanced measuring instruments, which are



inspected regularly by independent, accredited laboratories. All test stands and models meet the requirements of the cur-

rent IEC standard 60193 "Hydraulic turbines, storage pumps and pump turbines – Model acceptance tests".



Abrasion test stand

On investigating hydro-abrasive erosion ANDRITZ HYDRO cooperates closely with its hydropower customers. As a result of this cooperation comprehensive knowledge has been gained on the behavior of coating materials under operating conditions. Damage mechanisms have been analyzed thoroughly and areas with high improvement potential with regard to maintenance cycles have been identified. In order to meet customer requirements with regard to availability and productivity, the following research objectives have been defined:

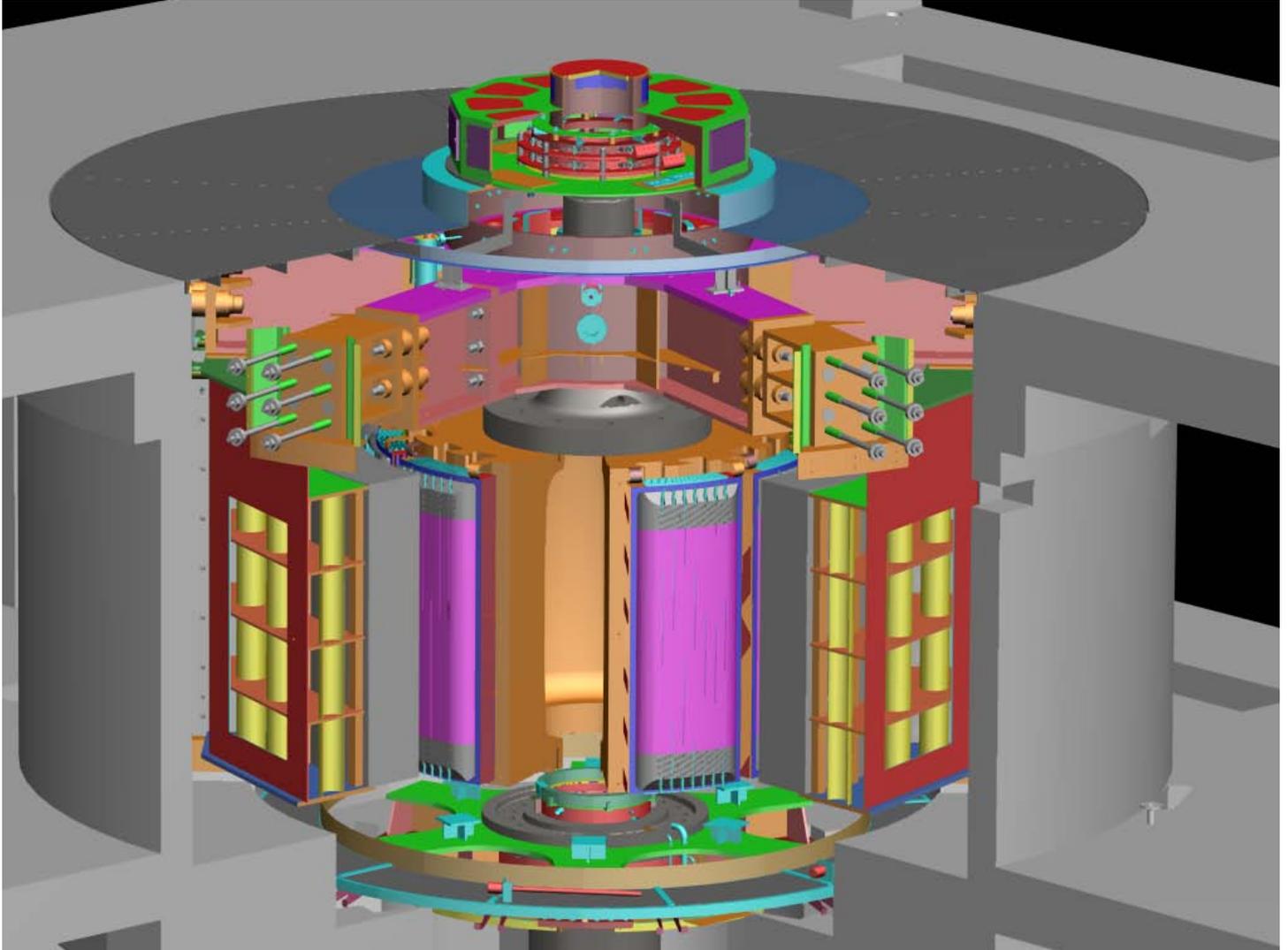
- Develop coatings with higher durability
- Extend maintenance intervals by means of component-specific design and coating (e.g. splitter edge of Pelton buckets)



In order to achieve these objectives, ANDRITZ HYDRO set up a coating test stand to simulate conditions as similar as possible to the real plant in 2010.



Generators



Modern, heavily used large generators are exposed to different multi-physical stresses. It is not only the combination of thermal and mechanical influences that presents a particular challenge in designing reliable generators with a long lifetime, but also the occurrence of these influences together with the effects of electromagnetics and of insulation and ventilation systems.

Electromagnetics

2D and 3D FE programs are used to improve the accuracy of the calculated electromagnetic parameters (losses, reac-

tances and field currents) and to optimize generator components. The results of these calculations are used together with test data to calibrate fast programs which are necessary to calculate many different design options during the electromagnetic layout of a new generator.

Insulation technology

The high voltage insulation of the stator windings is one of the most critical and important key components of large rotating electrical machines and influences life time and reliability. ANDRITZ HYDRO produces

coil and bar windings and can deliver them using VPI (Vacuum Pressure Impregnation) as well as in Resin-Rich technology. Machines in the lower power range are manufactured using Global VPI Technology.

All insulation systems are thermal class F with excellent electrical, thermal and mechanical characteristics and with high reliability. All systems are based on mica tapes, impregnated with epoxy resins. All of them fulfill the highest requirements of international standards including IEEE, IEC, KEMA, etc.

Fluid film bearing technology

The prediction of temperatures and losses of thrust and guide bearings of hydroelectric units is a prerequisite for the safe operation and moreover the fulfillment of technical specifications.

Continuous development of most modern numerical simulation methods for the fluid film as well as the total oil circuit including the periphery enables the optimization of the bearing behavior while reliable operation over the total lifecycle is guaranteed. The analytical methods developed consider complex, time dependent interaction of fluid dynamics, thermal and structural phenomena.

Ventilation and cooling

Fluid dynamics and heat transfer of generator components and of the total ventilation circuit are being calculated with three-dimensional methods. Characteristics derived from these investigations are transferred to components of flow networks, which allow the optimization of the complete ventilation circuit. The exact determination of the air flow rates combined with

the calculation of the heat transfer provides the basis for effective loss reduction and for the evaluation of temperatures of active parts.

Calculation tools are permanently being improved by measurement data acquired during commissioning and factory test runs.

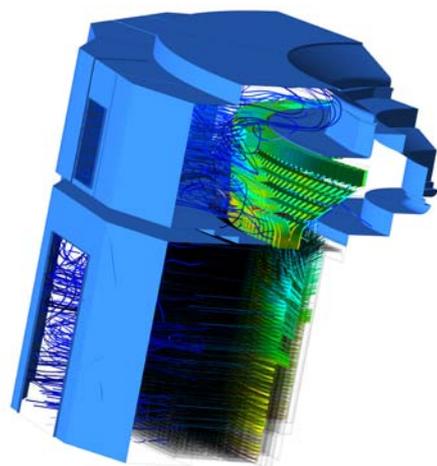
Mechanical Developments

Components of hydro generators are subject to high centrifugal, thermomechanical and, electromagnetic loads. The resulting forces either act constantly, cyclically or dynamically. Fatigue assessment must therefore be carried out in addition to static stress analyses. Among many parts of the generator the dynamic behavior of rotor, stator and stator endwinding will be calculated individually in order to ensure silent operation with low vibrations.

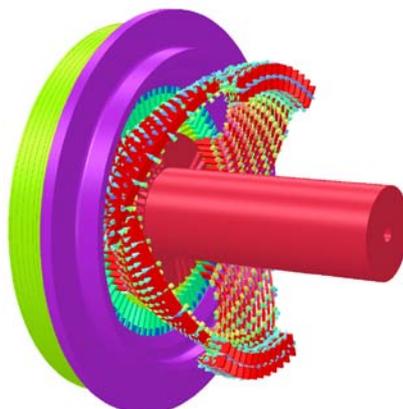
Stress and fatigue assessment as well as vibration calculations are performed with tailor made in-house calculation tools, which are continuously being upgraded and improved. Measurement data from site as well as from the test facility are used for validation.

Turbo generators

As regards of structural mechanics and vibrations, in particular the stresses due to the high centrifugal forces in the rotor and the vibrations due to electromagnetic forces in the stator are analyzed with 3D FE models. In the field of electromagnetics the calculation of the magnetic field, losses, and forces in the stator end region are of high importance. The accurate calculation of the air flow and temperatures in the generator enables with the electromagnetic and mechanical calculations the optimization of the generator.



▲ Cooling air flow path



▲ Forces at the end winding of a Turbo generator

Test Stands in the Generator Technology

The rotors of rapidly running generators, such as low-pole motor generators for pumped-storage applications or turbo-generators are exposed to extreme centrifugal forces. In addition to structure analyzing computations these components can be tested in a centrifugal tunnel at speeds higher than the maximum operating speed.

The centrifugal tunnel is used to test the rotors of turbo generators. Apart from the centrifugal force tests computer-assisted balancing is performed as well as electrical measurements on the rotor windings under extremely high centrifugal forces. This ensures smooth and reliable operation at the site of installation.



▲ Rotor of a Turbo generator in the balancing pit

VPI laboratory impregnation plant

HV insulation technology improvements and developments are tested and optimized in a VPI (Vacuum pressure impregnation) test impregnation plant before trans-

fer to the manufacturing process. Thereby it is possible to do the investigations in a laboratory or pilot scale, independent of the production facilities. Beside variation and

optimization of process parameters the VPI laboratory plant is used also for the development of prospective resins, insulation materials, systems, and build-ups.



Bearing test stand

A large bearing test rig for combined thrust and guide bearings allows tests of new bearing concepts under realistic operating conditions (speed, thrust, temperatures). Besides the evaluation of load limits the influence of loss reducing design measures can be determined. Detailed investigations of plastic pad coatings require extensive measurement campaigns.

The measurement data acquired is utilized for the validation of numeric simulation tools, which are used during the design optimization process.

Large equipment test bay

The large equipment test bay is used for performance tests and special measurements in acceptance tests as well as for prototype testing of newly developed turbo-generators.

Before release for series production a prototype test is performed, in which all newly developed turbo generator types are fitted with over a thousand measuring points, whose signals are evaluated and analyzed using advanced computer-based measuring technology.

High-voltage and insulation test

Life endurance tests are done with multiple nominal operating voltages to subject the winding insulation to accelerated artificial ageing. These investigations are done on HV lifetime test stands.

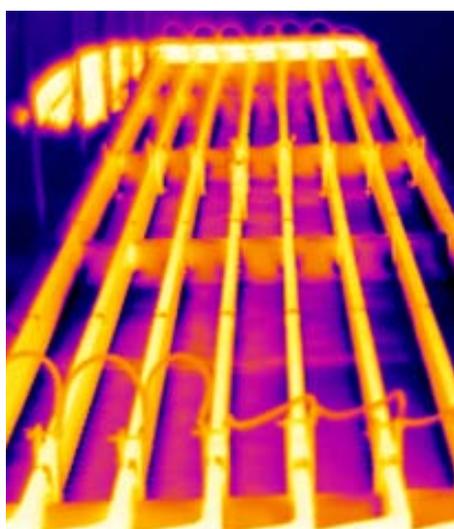
Lifetime laws are used to evaluate the quality and life expectancy of the windings.

The tests are performed in compliance with applicable international standards and may be carried out both at room tem-



perature and at the generators' operating temperatures. Regarding thermocyclic investigations test stands are available, where the windings are subjected to tem-

perature cycles as defined in international standards. The insulation quality is evaluated by dielectric and lifetime tests subsequently.



◀ Insulation test ▼



Automation



The target of R&D in automation is the optimization of process-related plant information flow. Parallel to hydraulic and electric energy, there is a permanent flow of information in the power station, which manages, controls, optimizes, and protects this energy conversion process.

ANDRITZ HYDRO continuously develops new products and procedures to optimize this information flow in the power stations. R&D handles projects in all areas of the product range – from protection, excitation, system control and turbine controllers to overall process control in the power station control rooms.

Automation is characterized by high technological dynamics in electronics and IT (information technology). This rapidly progressing technological development presents R&D with three central challenges:

- Telecommunications as innovations driver
- Integration on a standard system platform
- Modern operating technologies

Telecommunications as innovations driver

Today revolutionary innovations in basic electronics and IT research originate mainly from the consumer goods industry, in particular telecommunications and the IT market. These markets, however, are characterized by considerably shorter innovation cycles than the hydropower market. The primary automation components in a hydropower station are designed for the long term; the basic technical components of automation (microprocessors or, in control rooms, even commercial computers) have innovation cycles of some months or a few years.

ANDRITZ HYDRO R&D meets these challenges with a long-term platform strategy. The appearance and interfaces of these products have remained unchanged and also compatible for a very long time, however, the technical components inside are subject to continual innovation. The technological dynamics described allow also innovations that were inconceivable a few years ago – R&D uses these consistently and drives them forward. Examples of this are the central control of large-scale series of hydropower stations, with over 100 power stations controlled from one central station, or mobile control room solutions for unstaffed power stations.

Integration on standard system platform

The automation components in a power station have long, different technical histories and have mostly been implemented with different platforms.

The use of electronics and advanced communication technologies allows their basic structure to be more and more standardized. ANDRITZ HYDRO is working consistently on combining these components on a standard automation platform in order to achieve smooth, integrated interaction of all components – the newly developed product platform HIPASE is the result of these efforts.

Modern operating technologies

The hard- and software solutions used in office communication and the consumer goods industry have revolutionized the technology and operation of control rooms and operating panels. R&D activities focus on the combination of these technologies and the functional-organizational requirements in a hydropower station. The result of these development activities is 250 SCALA – the SCADA system of ANDRITZ HYDRO.

System simulation

The focus of system simulation has been on the steady-state and transient performance of the hydraulic equipment in the past. Additionally to this, the interaction between all the components of a hydropower station and especially the influences of the grid and of the grid connection need to be taken into account for a reliable operation.

Since hydropower stations in contrast to thermal power plants are capable of rapidly adapting production to current demand, hydropower stations are gaining importance for grid control. As a consequence, even run-of-river power plants, which were previously only used as basic load stations, are increasingly used for primary or

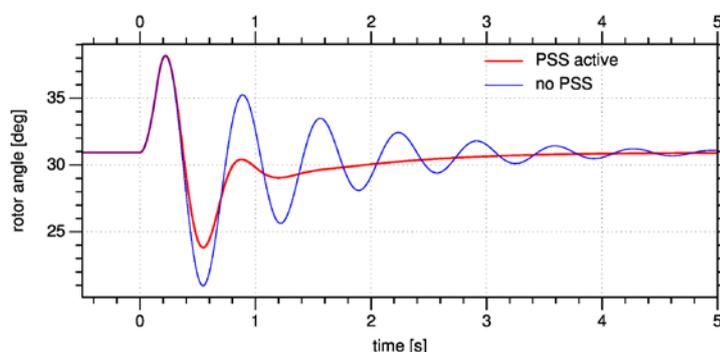
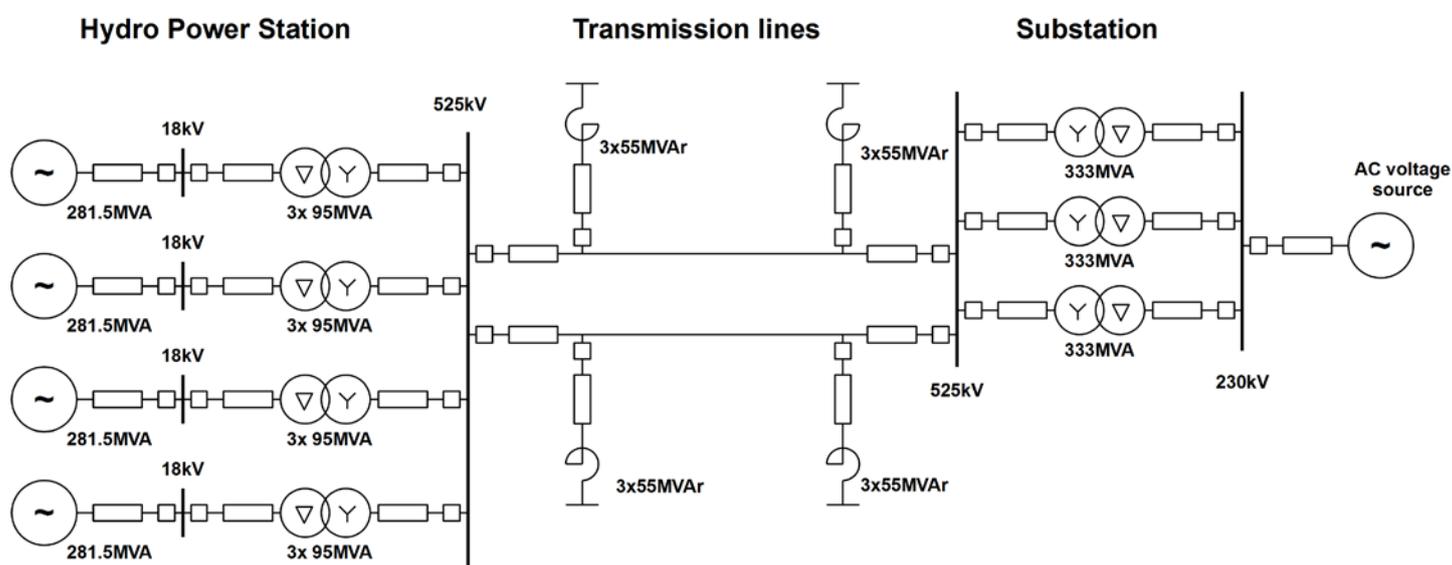
secondary control. In addition, power stations have to meet more stringent requirements by grid providers. The capability for black start and stand-alone operation in small networks are also frequently of significance. Since the reliability of a power station must not be adversely affected in any way despite stricter requirements, the risk of pressure oscillation and impermissible pressure and speed rises has to be analyzed intensely.

For this reason, careful analyzes and new solutions have to be developed for power stations with critical water supply systems. It is important that all critical aspects are considered in system simulation at the

same time – from the water supply system to grid connection, including the precise modelling of turbines, generators and control technology.

The effects of new technical solutions such as hydraulic units with variable speed are studied and analyzed by means of precise and cross-system simulation.

ANDRITZ HYDRO is both using existing simulation models and takes an active part in developing and adapting the models and the simulation software to be prepared to plan, install and equip hydropower plants even with challenging grid or operation requirements.



Collaboration with universities

Research and development take place in an international network of research partners. ANDRITZ HYDRO initiates and participates in research projects with universities active in the relevant technologies. In order to meet the high requirements of our customers, we continuously extend the limits of research. In close cooperation with universities we address current issues and future technologies in project work. In this context we also frequently conduct basic research, which may occasionally not be considered in our project-driven daily business. In addition the cooperation with universities offers valuable opportunities to make contact with the top-level graduates who are best qualified for tackling future tasks with ANDRITZ HYDRO. The decentralized R&D structure allows close contact with universities and local research funding institutions, which is of particular significance in countries with a high hydro-power potential.

Germany

- University of Applied Sciences Konstanz, www.htwg-konstanz.de

France

- Ecole Centrale de Lyon, www.ec-lyon.fr

Greece

- National Technical University Athens, Parallel CFD & Optimization Group
<http://velos0.ltt.mech.ntua.gr/research/>

Austria

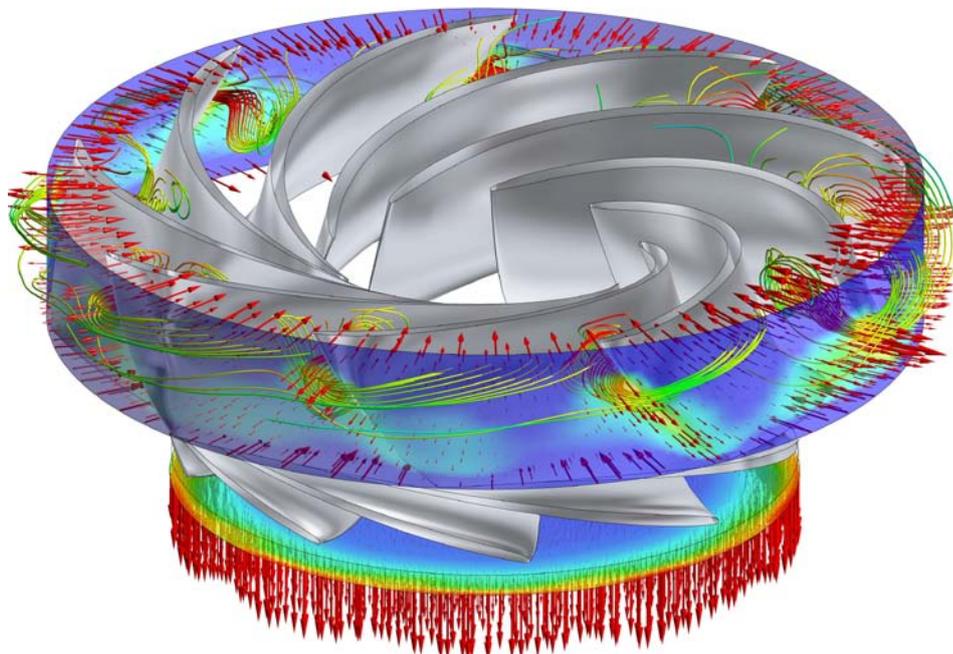
- Johannes Kepler Universität Linz, www.jku.at
- Technische Universität Graz, www.tugraz.at
- Technische Universität Wien, www.tuwien.ac.at
- Montanuniversität Leoben, www.unileoben.ac.at

Canada

- École Polytechnique Montreal, www.polymtl.ca
- McGill University Montreal, www.mcgill.ca
- University of Waterloo, www.uwaterloo.ca
- Université Laval, Québec City www2.ulaval.ca
- École de Technologie Supérieure, Montréal, www.etsmtl.ca/

Switzerland

- Swiss Federal Institute of Technology Zurich, www.ethz.ch
- École Polytechnique Fédérale de Lausanne, www.epfl.ch
- Luzern University of Applied Sciences and Arts, <http://english.hslu.ch/>



International norms and standards

All work processes within ANDRITZ HYDRO are audited and certified by recognized inspection institutes for quality, safety, and environmental management. Such certifications are conducted at all sites at regular intervals and form the basis that enables ANDRITZ HYDRO customers to count on highest quality of internal processes and accomplished products in the future.

ANDRITZ HYDRO is very active in various research projects regarding norms and standards, initiated by international organizations. In this regard, for instance, scientific topics in the field of hydraulics are addressed in various research groups within IAHR (International Association for Hydro-Environment Engineering and Research). The results are then used by various working groups of the IEC (International Electrotechnical Commis-

sion). Participation in these internationally staffed working groups offers the opportunity to contribute expertise and experience. Furthermore there is a lively exchange of ideas with excellent scientists and respected university professors. In most cases development of a joint product and/ or revision of an already acclaimed set of rules is a challenging and, at the same time, a fulfilling task.

The achieved standards result in better comparability and reliability and they also facilitate everyday work, because they are recognized internationally and hence constantly referenced. In consequence, the appropriate standards are always applied to the performance and evaluation of model and plant tests, and of course all ANDRITZ HYDRO test stands meet the specified requirements.



