MGT Expertise from Universities and R&D Institutes

Content:

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LONDON

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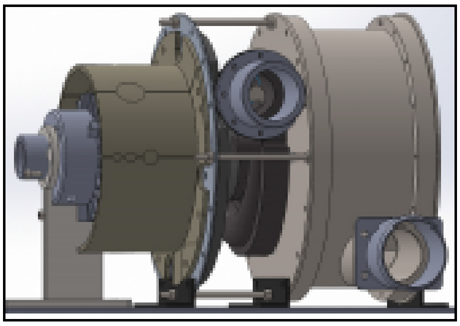
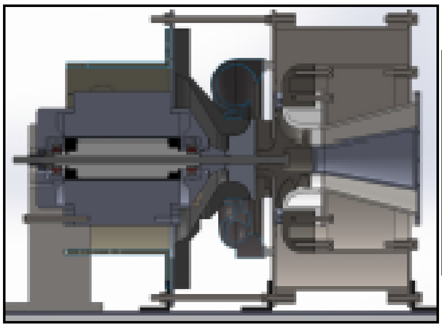
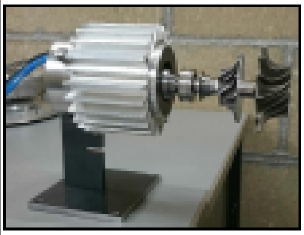
Research Activities and Facilities Relevant to Micro-gas turbines

Infrastructure

- Continuous programmable high pressure air supply providing dry air at 25°C at pressures up to 10 bar and mass flow rates of up to 1.5 kg/s supplied to all test cells.
- High pressure shop air up to 7 bar and 0.2 kg/s
- Chilled water for cooling purposes with thermal capacity of 350 kW
- High temperature exhaust tunnel capable of handling large volumes of exhaust over 1000°C.
- Workshop with high spec machining equipment including CNC capable of manufacturing large array of parts for test rigs.

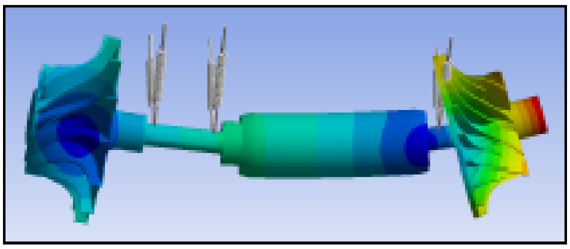
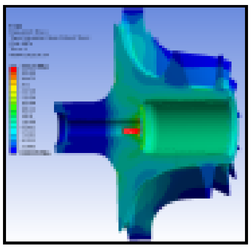
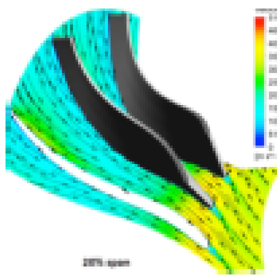
Micro-gas turbine test Cells

- High speed test rig for compressors and turbines for capacities of up to about 0.3 kg/s flow rates (see Figure below) coupled to a high speed motor generator.
- Micro-turbine test rig with both gaseous and liquid fuels
- An array of measurement equipment including flow meters, thermocouples, and pressure transducers.
- Optical flow diagnostics equipment is also available within the laboratory.
- Low speed balancing machine
- Impedance sensors for measurements of shaft vibrations.

Computational and analytical tools:

- In house design and off design cycle analysis and system optimisation tools
- Compressor and turbine design and optimisation programmes complemented by CFD
- Vibration and rotor dynamics analysis expertise.

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Thermochemical Power Group

University of Genoa
Polytechnic School

Thermochemical Power Group (TPG)

The Thermochemical Power Group (TPG) is a multidisciplinary research group based at the Polytechnic School of the University of Genoa (Italy). The TPG was established in 1998 from the idea that the study of efficient energy conversion requires thermodynamic, chemical, energy, exergy, and thermoeconomic-environomic skills. In June 2004, the TPG has become the first Rolls-Royce University Technology Centre on Fuel Cells in the world. At the moment, TPG is constituted by 25 people that produced (in the last 15 years) about 10 patents and 210 international papers. Moreover, TPG was involved in 15 European projects based on both theoretical and experimental activities in the advanced energy system field (fuel cells, hybrid systems, advanced mGT based cycles, renewable energy, hydrogen generation, energy storage, smart grid management, etc.). The main TPG's partners are: Ansaldo Energia, E-ON, Istituto Tecnologico de Aeronautica (BR), LG Fuel Cell Systems, PTI (Paraguay), Rolls-Royce, U.S. DOE – NETL, VTT, Universities: Manchester (UK), Cranfield (UK), MDH (S), Seville (E), Brussel (B), Shanghai (Ch), West Virginia (US), California Irvine (US).

Facilities by TPG (both software and hardware)

The TPG has a strong experience in energy system simulation and optimization that has been included in the following in house software:

- W-TEMP (thermodynamic and thermoeconomic analyses for energy systems);
- TRANSEO (dynamic, transient and real-time calculations for turbine based plants);
- W-ECoMP (multi-level optimization for size and management strategies related to energy systems).

Moreover, the TPG has developed several experimental facilities for innovative energy system improvement (analysis and optimization). The main test rigs installed in TPG's laboratory are:

- Microturbine test rig (T100);
- FC/mGT Hybrid system emulator test rig;
- Absorption chiller test rig;
- Smart Polygeneration Microgrid serving the Campus (Fig.1);
- Renewable energy storage laboratory;
- CSP emulator rig (high temperature storage system);
- Wave flume facility for sea wave energy converters;
- Fuel-cell-ready mGT hybrid system (work in progress).

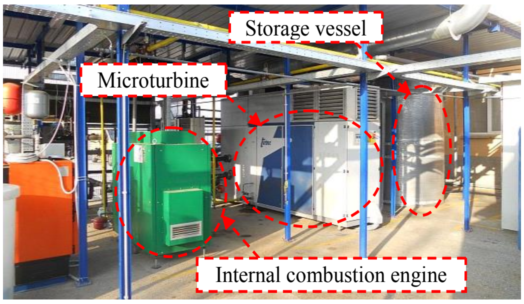

Figure 1. TPG's generators for the Smart Polygeneration Microgrid.

Main collaboration proposals

TPG can share several skills in two different forms: direct contract, activities as a partner in projects (H2020 or other international funding schemes). TPG is also interest in collaboration projects related to staff exchange (e.g. Marie-Curie programs). This is a brief summary of possible collaboration fields:

- Microturbines including related components (e.g. recuperators, control aspects). TPG has a T100 machine fully instrumented and modified for complex cycle development, a second T100 microturbine that is operated in its commercial mode and three Capstone machines operating in a smart grid).
- Development of high temperature storage device for CSP applications (or other mGT layouts). An apt emulator test rig can be used for studying optimized management related to this device. Moreover, large scale demos can be designed and tested.
- Optimization and control activities (models and experiments) related to the integration of renewable energy sources in smart polygeneration grids, including energy storage.
- Hydrogen generation, management (including storage) and utilization. A demo rig can be developed to optimize these systems: renewable sources to generate hydrogen, storage and utilization management. Fuel cell improvement aspects can be included.

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KTH Royal Institute of Technology
Stockholm, SWEDEN

KTH Industrial Engineering and Management

Among others the Department of Energy Technology is working in the following fields.

1. **Aeromechanics and performance calculations**

2. **Aeromechanics and performance wind tunnel test**
   Experimental testing is performed amongst others in the Aeroelasticity test rig (AETR)
   AETR is a test facility for experimentally investigating aerodynamic damping in turbomachines. Aerodynamic damping is one of the ingredients in aeroelasticity and is of interest as it can lead to instability (flutter). AETR has been commissioned in 2003 and is world-unique as it allows studying the aeroelastic phenomena at relevant operating parameters while providing a great experimental freedom.

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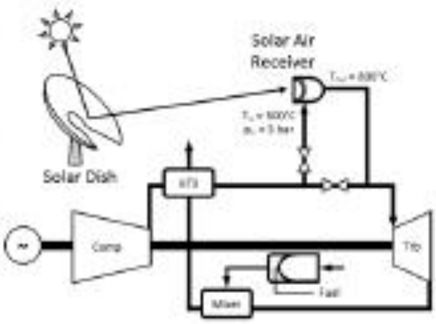
3. **MGT control and high speed generator technology**

4. **Solar MGT integration and testing**
   Experimental testing is performed in the High-Flux Solar Simulator (HFSS)
   The Department of Energy Technology operates a HFSS, capable of recreating in a controlled manner the irradiation conditions under which solar receiver components operate, in order to investigate the behavior of these components and the integration with MGT power conversion cycle. One focus is placed on the control and integration of the different components in the power conversion cycle due to the varying nature of the solar resource.



ENEA, Casaccia Research Center, UTTEI-COMSO, Rome - ITALY

Micro-GT Facilities, Expertise and Activities in ENEA

Plants

- AGATUR: Turbec T100 GT aimed at testing the engine coupling with a nearly CO2 working fluid using oxy-combustion of natural gas.
- ZECOMIX: coal gasification, CO2 capture with solid sorbents (Calcium looping technology), syngas production and final combustion in a Turbec T100.
- COMET-HP: test facility equipped with an ANSALDO V-64-3A burner aimed at monitoring combustion instabilities by means of advanced sensors for their real-time detection. The plant can work with natural gas, potentially up to 10 bar and 1MWt.
- MICOS: test facility to study Trapped Vortex Combustors with natural gas (100 kWt).
- IDEA: test facility to study H2/air combustion at 1 bar also with steam (100 kWt).

Experimental Diagnostics

- Laser and spectroscopic techniques: PIV, LIF, CARS, Raman.
- Standard sensors: thermocouples, pressure transducers.
- ODC (Optical Diagnostics of Combustion): ENEA's optical system for real-time monitoring of combustion.

Computational Fluid Dynamics

- ANSYS: commercial software.
- OpenFoam: free software.
- HeaRT: in-house code for LES and DNS of turbulent reactive and non-reactive flows, at high and low Mach numbers. Both ideal and real gas equations and related transport modelling are implemented, extending the simulation capabilities up to supercritical flows.
- High-Performance Computing: several parallel platforms, among which CRESCO3 with its 2016 cores (20 TFlops) and CRESCO4 with its 4864 cores (87 Flops).

Cycle Analysis

- Both static and dynamic cycle analysis are performed by means of the CHEMCAD commercial platform including embedded in-house models.

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Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center
Institute of Combustion Technology

The DLR Institute of Combustion Technology carries out research and project work on the design principles of technical combustion systems with about 95 members of staff. The main research topics include

- **Fuels** (Natural Gas, Syngas, H_2, Kerosene, Oils, Synfuels)
- **Emissions** (NO_x, Soot, UHC, CO_2)
- **Unsteady Combustion Processes** (Ignition, Extinction, Thermo-Acoustics, Noise)
- Fuel and Load Flexible **Burners and Combustor Systems**
- **Distributed Energy Systems** (micro gas turbines (MGT)-CHP, Hybrid Power Plant, APUs).

With strong interdisciplinary competences in chemical kinetics, numerical simulation, diagnostics, combustor and MGT test rigs, combustor design, and MGT systems, the institute is spanning the bridge from combustion science to combustion technology up to field demonstration plants.

The institute operates several **atmospheric** and **pressurized combustor test rigs** with up to 2 MW thermal power, and pressures up to 40 bar. The combustor test rigs can be operated with combustor inlet temperatures up to 1070 K and with conventional and alternative gaseous and liquid fuels. Experiments are performed using advanced laser-based and optical measurement techniques including **high speed PIV & PLIF, Raman, CARS, OH*/CH* chemiluminiscence, etc.** to measure flow field, temperatures, species concentrations and flame structures and **exhaust gas analyses**. For the development of combustor systems for MGTs, the optimization of conventional MGT-CHP systems, and the development of innovative MGT/CHP and APU concepts, various detailed instrumented combustor and MGT test rigs are available. These include test rigs based on a **Turbec T100 (Ansaldo),** including an optically accessible combustion chamber, an **EnerTwin (MTT)**, a **GTCP38-28 (Garrett)** and a **C30 (Capstone**; planned) covering a range in electric output from **1 to 100 kWe**. Simulation of MGT power plants is performed using in-house numerical thermodynamic cycle tools. For the development of combustor systems, commercial as well as in-house numerical CFD codes (THETA (Turbulent Heat Release Extension of the TAU Code) using e.g. complex chemistry with multivariate assumed JPDF model) are used.

Current research projects are focussed on:

- Power station concepts:
  - **Hybrid Power Plant** (coupling of pressurized SOFC & MGT)
  - MGT based on the **Inverted Brayton Cycle** for small MGT-CHP systems with **1 kWe**
  - **Auxiliary Power Units**
  - **MGT-based range extender** (interurban vehicle)
- Combustion systems for natural gas, wood gas, VOCs (Volatile Organic Compounds), Diesel, Kerosene, SOFC-off gas, exhaust gas recirculation using FLOX® and swirl stabilized combustion concepts

Research partners (among others): Dürr, MTT, Hiflux, MAN, Alstom, Siemens, RR, MTU, EnBW

Expertise

The Research Group of Fluid Machinery and Energy Conversion Systems of the Department of Engineering (DING) is actively involved in the following research topics:

- Energy conversion systems: optimization of design and operation of power plants, design and analysis of plant components (heat exchangers, compressors, steam turbines, gas turbines, cooling and so on), development of methodologies and models for status recognition and diagnosis of GT components, advanced power production systems;
- Development of small turbo-expanders for steam and organic working fluids, cold tests of turbochargers;
- Assessment of innovative GT cycles for solar applications;
- Theoretical and experimental investigations of fuel emulsification and combustion of emulsified fuels
- Development of high-temperature solar receivers for Dish-MGT systems, including thermal energy storage.

Test facilities

- Test bench for the development of unconventional micro turbo-expanders:
  Such a test bench is equipped with the necessary instrumentation to map prototype performance. It has been successfully used for the setting up of prototypes for innovative energy saving techniques in cryogenic industrial plants.
- Solar Facilities:
  A 1,5 kW solar energy capture and concentration facility is available for high temperature tests on solar receivers and reactors.
  Moreover, two solar simulators are available in the Dept. labs: one for small-scale experiments (in the order of 400-500 W) and a 25-30 kW modular structure (each module is about 5-6 kW) to test receivers, reactors, concentrated PV panels, solar MGTs etc. at medium-high temperature.
- Facility for emulsion characterization:
  The facility is organized with a test bench for prototype of on-board emulsification systems for liquid fuels adopted in GTs and Diesel Engines.
- Test bench for steam traps:
  Such a test bench has been set up in conformity with national rules (UNI EN 27841) to measure steam trap performance and to evaluate possible component upgrades.
- Inverse cycle bench for refrigerant tests and for the development of ORC volumetric machines and turbomachinery.

Ongoing Work

At the moment, the Research Group is involved in the OMSoP project as WP leader for the techno-economic optimization of the Dish-MGT plant. In particular, its efforts are focused on the system thermodynamic analysis and optimization. Moreover, another relevant activity is the design of a solar receiver integrated with a short-term storage system.

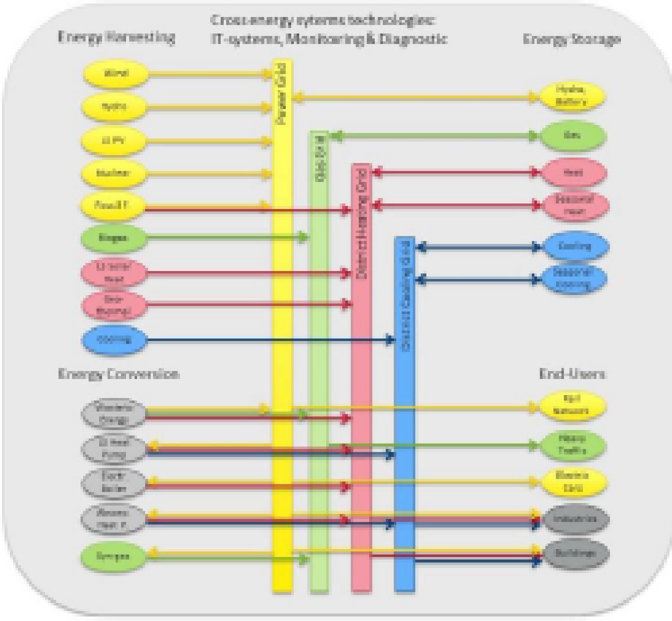
A second relevant research topic is the development of an innovative system for energy saving in cryogenic plants based on automotive turbocharging concepts. In particular, the Research Group is involved in the national project "COLD ENERGY – Development of a recuperated cryogenic plant and development of the compressor-expander-heat exchanger group (CEG)" and it is the leader partner for the development and prototyping of the CEG.

New Energy Group
Energy Department
International Research Institute Stavanger
Stavanger / Norway

The New Energy Group of the International Research Institute Stavanger (IRIS) has experience in the area of Micro Gas Turbines (MGT) and is also closely cooperating with the University of Stavanger (UiS) in the centre for sustainable energy solutions (cenSE). Activities ongoing are in the field of:

1. Monitoring, diagnostics and early warning for gas turbines and energy systems using the approach of artificial neural networks. The technology was applied to the MTG test rig using a T100 gas turbine as well as stationary GTs.

2. Within the Norwegian funded project "Intelligent Biogas Fuelled Energy Conversion Technologies" were theoretical and experimental investigations on the stability range of an un-modified GT for variations of fuel composition performed. Fuel gas compositions were based on various mixtures of natural gas and biogas, using a gas mixing station to continuously vary the fuel composition.



3. Current ongoing activities are closely connected to MGT applications in the frame of smart energy systems combining various energy sources and energy carriers (see graph on the right).

4. Energy systems integration using, amongst others, MGTs for CHP applications. Experience exists for:

    a. Modifying and integrating a MTG with a solid oxide fuel cell covering component development (e.g. new combustors, control and auxiliaries), testing and commissioning

    b. Modifying and integrating a MTG with a molten carbonate fuel cell covering component development (e.g. new combustors, control and auxiliaries), testing and commissioning

    c. Conceptual layout of a MGT / solar hybrid to be positioned on a solar tower, using experience gained in a. and b.

    d. MGT application concepts for waste heat recovery from Aluminium furnaces

    e. Close to MGT experience resulting from various projects in the area of non-motor applications of turbo chargers. Activities in this area were closely connected to energy efficiency improvement of industrial processes

RSE
Ricerca Sistema Energetico

For several years, in the frame of national founded projects, RSE has been actively engaged in identifying possible solutions to improve the performances of micro-turbines and to extend the use of this CHP technology to a wider class of solid fuels such as biomasses and wastes.
The activities have been mainly focused on three topics:

- Identification of plant configurations to increase the MT efficiency
- Studies on materials and coatings for a ceramic MT
- Plant configuration and materials issues related to externally fired MT

Identification of plant configurations to increase the MT efficiency (activity completed)
In particular, a specific attention has been paid to three main solutions: Inverted Brayton Cycle, Humidified Brayton Cycle and a regenerative Brayton cycle with ceramic components.
The first two solutions allow to reach an increase of the efficiency of 3-5 points in the best cases: only the adoption of ceramic components (turbine and possibly recuperator) could lead to a higher efficiency in a CHP application.
A numerical model of the Turbec T100 microturbine, installed in RSE area, was developed by Thermoflex® and validated by comparison with the results of previous experimental activities. The operation of the unit was simulated at nominal and partial load and the performance of the unit, in different configurations, was investigated. Starting from this first model, a new model of a ceramic microturbine was finally developed; different simulations were performed in order to evaluate the influence of the turbine inlet temperature (TIT) on the plant layout. An optimal target for Turbine Inlet Temperature has been identified.

Studies on materials and coatings for a ceramic MT
Efficiency of microturbine can be improved by the introduction of new materials in the manufacturing of the most service stressed components. Depending on technical engineering solutions applied in microturbine design, the substitution of metal alloys with advanced ceramic materials in turbine components and/or regenerating heat exchanger can give rise to an increase in thermal efficiency in the range from 5 to 10%.
The main limitations for a commercial development of these products are related to the high cost of manufacturing components of complex shape, with very small geometric tolerance, and to some improvements of materials properties that are still required, especially in term of resistance to oxidation/corrosion combined with satisfactory mechanical strength at high temperatures.
For a couple of years RSE has investigated ceramic materials as silicon nitrides or derivative materials as SiAlON by mechanical properties characterisation, microstructure investigation and resistance to oxidation with the exposure in a high flow rate burner rig. As an alternative to the improved oxidation resistant silicon nitrides, the application of environmental barrier coating (EBC) to ceramic based components has been considered too, and the burner rig exposure experiments are presently ongoing on coated specimens.
As experimental capacity, useful for these activities, RSE can offer: three or four point bending tests from room temperature up to 1200°C for bulk ceramic materials and freestanding coatings, toughness tests on massive and thin ceramic specimens, exposure in a high flow rate burner rig simulating combustion conditions, with tuneable steam content at temperatures up to 1400°C.Furthermore, RSE has a Spark Plasma Sintering (SPS) equipment for sintering innovative bulk ceramic formulations in collaboration with ceramics and/or MT manufactures.

Plant configuration and materials issues related to externally fired MT
An interesting evolution of natural gas MT consists on the external combustion MT (Externally Fired Micro Gas Turbine), that, although still being in the development phase, could ensure the typical advantages of the gas turbines technology, together with the exploitation of "carbon neutral" solid fuels. The principle the technology is based on is very simple and consists of a complete separation (using dedicated, high temperature heat exchangers) between the fluid that operates the working cycle (air) and the combustion products gas stream, that transfers heat to the air to be expanded in the turbine. An EFMGT can perform a regenerative Joule cycle, in which an exchanger instead of a combustor is introduced with the purpose of heating the air coming from the compressor before it expands in the turbine. However, even if this kind of configuration has been studied and developed for a long time, the temperature limits imposed by the materials used for heat exchangers construction, and oxidation/corrosion phenomena they are subjected to, are still extremely critical factors in terms of performance and reliability. For a better understanding of these issues, RSE signed a cooperation agreement for monitoring the mini combined cycle owned by an Italian farm. The system consists of two external combustion MT (80 kWe nominal power each), fueled by wood chips from the forestry sector, and a 110 kWel nominal power Rankine organic fluid

cycle, suitable for exploitation of low enthalpy heat sources, in this case the air at MT outlet. The activity has provided a complete heat and mass balance of this plant and has highlighted current operational limits.
Characterization tests were performed considering working conditions close to the nominal design ones:
the results have shown that increasing the temperature of intake turbine air is really beneficial in order to obtain higher and more competitive performances. Increasing air temperature, however, will promote the oxidation phenomenon affecting heat exchangers tubes, causing higher quantity of solid particles to reach the MT and producing erosion damages.

For a better investigation of solid particle erosion phenomena, and in order to identify possible solutions in terms of advanced materials and protective coatings, RSE installed air cooled mockups inside the external boiler to monitor oxidation progression on the air side of candidate materials and coatings.

Furthermore, experimental activities aimed to estimate coatings oxidation kinetics and the severity of the erosion rate of materials used for manufacturing turbine components as a function of the different operating conditions are currently in progress.

In this frame RSE can offer Lab infrastructures for carrying out high temperature oxidation/ hot corrosion studies as well as a high temperature solid particle erosion testing facilities.

For in field monitoring of material degradation, RSE has developed corrosion probes enabling to quantify damage mechanisms as a function of the different operation conditions, in terms of temperature and fuel composition.

Propulsion and Power

Research on next-gen and innovative propulsion and power systems and components
Efforts are devoted to the development of new methodologies for the design of power and propulsion systems and components, whereby optimization techniques are applied to system models integrating detailed models of components (e.g., turbomachinery and heat exchangers), and to the automated fluid dynamic design of turbomachinery. Much of the work is performed in collaboration with industrial partners.

Aircraft Propulsion
Modelling and simulation work is performed for development programs of novel engine designs and for analysis of engine health in the maintenance environment. Novel aircraft propulsion concepts are analyzed for integration into future aircraft designs. In this respect, our studies on the Multi-Fuel Blended Wing Body passenger aircraft, propelled by a new LNG-Biofuel powered hybrid turbofan engine, stand out.

Novel Thermodynamic Cycles
We develop new knowledge on the fluid dynamics and thermodynamics of dense vapors and supercritical fluids by performing theoretical, numerical and experimental studies, and apply it to the study of innovative technologies like the mini-Organic Rankine Cycle (ORC) turbogenerator or the supercritical CO_2 Brayton cycle system. With these technologies, new ultra-efficient concepts for propulsion systems are pursued, like the Combined-Cycle engine for aircraft and the Combined-Cycle Powertrain for trucks.

Micro turbines
Micro gas turbine technology has a specific focus at Propulsion and Power group. Research is performed for design and optimization of systems/cycles, turbomachinery and combustion of advanced micro and mini gas turbines. For power generation micro turbines, turbomachinery designs are optimized using advanced CFD simulations. For aircraft propulsion, research is focused on high-efficiency micro turbines for UAVs.

Modelling and simulation
The group has a substantial role in the development of the GSP Gas turbine Simulation Program (www.asimptote.nl/software/GSP-DUT). GSP has global recognition in the gas turbine community as a versatile gas turbine system simulation tool. System simulation work is performed for engine diagnostics (gas path analysis), analysis and optimization of combined cycles, including novel concepts with ORCs as gas turbine bottoming cycles.
CycleTempo (www.asimptote.nl/software/cycle-tempo/) is a tool for modelling of energy systems on the highest level including combined cycles.
FluidProp (www.asimptote.nl/software/fluidprop) is a software tool to generate fluid properties of a variety of fluids such as those used for ORC's.
The group has successfully demonstrated an breakthrough integrated modeling environment for propulsion and power system simulation based on the Modelica language: steady on- and off-design and dynamic simulations can be be performed within one single environment, which also supports integrated optimization.

Facilities
The group has a unique test facility for characterization of organic fluid gasdynamics of organic fluids. In addition, a new Lab is in construction: two new facilities will be able to measure supersonic flows of organic vapor and test mini-ORC turbomachinery. In addition, a test facility for radial micro-compressors is available. For the future, test facilities for combustion and small gas generators are envisaged.

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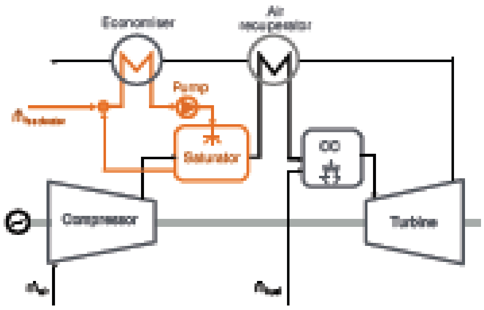
Micro Gas Turbine research at Vrije Universiteit Brussel

Current activities

In the current electricity market, flexibility in power generation is becoming increasingly important due to the intermittency of renewable energy sources. At BURN, research group of Vrije Universiteit Brussel (VUB), we investigate how to increase the attractiveness of micro Gas Turbines (mGTs) for Combined Heat and Power (CHP) by improving their flexibility.

In order to decouple heat and power production in an mGT, whenever the external heat demand is low, the waste heat in the exhaust gases—instead of blown off—can be used to generate auto-raised steam or hot liquid water, which is then re-injected in the cycle. This so-called humidification of the mGT will increase the electric efficiency, resulting in a higher profitability during periods with low or no heat demand.



By adding a saturation tower (orange) to humidify the air between the compressor and recuperator of a traditional mGT, the unit is transformed into an mHAT and its electrical efficiency increased.

Experience and infrastructure

Over 10 years experience in:

- Cycle optimisation using Aspen+.
- Experiments and conversion of mGT.
- Economic analysis to asses cycle viability compared to other technologies.

Moreover the BURN group has the following equipments:

- Turbec T100 mGT fully converted to micro humid air turbine (mHAT).
- Flameless combustion test bench (20 kW).

Project ideas and partner profiles

We are currently studying the dynamic behaviour of the mHAT cycle. We have also extended our research by including fuel flexibility and carbon capture. When power production from renewables peaks, electricity can be stored by producing non-conventional fuels, like hydrogen or ammonia. Thereafter, to shave the electricity demand, these fuels can be burnt in the mGT.

With regards to carbon capture, we are investigating how to reduce its cost by combining Exhaust Gas Recirculation (EGR) with humidification. Additionally, the captured carbon could be used in the production of alternative fuels.

We are looking for collaborations in the topics above and for partners with the following profiles:

- Fuel production from electricity.
- Carbon capture.
- Gas turbine components development for mGT, e.g. recuperator, control system, burner…

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Prof. Dr.-Ing. H.P. Berg

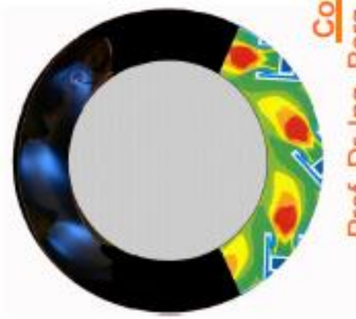
Brandenburg University of Technology Cottbus - Senftenberg

We are your partner for MGT research and development projects : MGT power systems, micro gas turbine design, combustion systems, light weight recuperator, optimizing air bearing , generator, power electronics, controls, hybrid applications (eg. MGT – SOFC) for **mobile and stationary applications.** (MTG = Micro Turbine Generator)

MGT- Research & Development

The chair has the departments internal combustion engines and gas turbines . For research and development projects several necessary calculation tools and test methods are available. A research and development area is also concerned with the micro gasturbines **MGT**. Air bearing for recuperated microturbines are in development for different customers. Based on the air bearing technology, hybrid applications are realized like **MGT - SOFC** energy converters (MTG-FC). This design will allow the highest possible efficiency .
In order to force this technology, Prof. Bergs **MICRO GAS TURBINE TEAM** cooperates with highly specialized partners for **SOFC SYSTEMS.**

MGT- Prototyping, System-/ Component Validation



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