Detailed information on energy research

Flexible turbomachines stabilise the power grid

ECOFLEX-turbo: Further development of power plant turbines for a grid with 80 % renewable electricity

BINE Information Service

In future, conventional power plants will need to become more flexible in order to compensate for the fluctuating power generation by renewables. This requires modified gas and steam turbines. These will have to work more frequently under partial load, with more start-up and shut-down cycles and function with changing fuels. AG Turbo has compiled the research and development objectives for these new framework conditions in the ECOFLEX-turbo programme.

In thermal power plants, steam turbines extract energy from hot vapour and gas turbines extract energy from hot gas. They form the heart of the power plants and their technical performance is crucial for the energy efficiency, application profile and emissions of the entire plant. Turbines convert the energy absorbed into electricity using generators. Until now, gas and steam turbines have been designed so that they operate as much as possible under full load without sudden switch-on and switch-off processes. This limits the material wear. In the future power grid- conventional power plants will perform new tasks. They will primarily offset the fluctuating electricity generated by wind power and photovoltaic systems in order to ensure a stable grid. To achieve this goal gas and steam turbines require further development. They must be more robust and adapted to deal with partial load operation, greater frequency fluctuations in the grid and fuel flexibility. Nevertheless, there should not be any reduction in the current standards regarding efficiency and emissions must be maintained.
The current ECOFLEX-turbo research programme run by AG Turbo compiles, in regard to the new framework requirements in the grid, the research objectives for turbomachinery until 2022 in more than 100 projects. For more than 30 years, leading German turbomachine manufacturers and more than 20 university insti-

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tutes, which account for more than two thirds of the subsidised turbine projects, have been working together in the AG Turbo alliance in order to conduct jointly pre-competitive research. These aspects concern both new plants and the retrofitting of existing turbines. German manufacturers are among the leading suppliers of turbomachines on the global market with a market share of approx. 30 %.

Partial loading places different demands on turbines

When turbines previously had to work for prolonged periods under partial load or under-frequency conditions, they would have been operating at the limits of or even exceeding their design parameter boundaries during certain phases. Each of these events shortens the service life of the components. Problems that can occur include, for example, undesirable oscillations and vibrations of the blades, thermo-acoustic phenomena and disturbances in the compressor. In addition, the efficiency of the plant decreases under partial load.

In future, turbines will be working more frequently under partial load conditions, will start up and shut down more quickly and, in the case of grid frequency drops, have to compensate for the power deficit in fractions of seconds, as required by the power grid. Nevertheless, they will still have to run economically in spite of this mode of operation. They will then be running permanently in operating conditions that they previously speeded through as quickly as possible during the start-up and shut-down phases. To achieve this, the compressors and combustion chambers must be more robust in order to cope with the growing number of start processes, load changes and operating cycles. New computer software will be required for analyses, design purposes and dynamic simulations, whereby the researchers want to calculate the real operating behaviour more precisely. The models should also help to improve the design of the components and the design procedures. This will reduce the need for time-consuming and expensive experiments and prototypes, and will enable more targeted work on the test rigs. The aim is that the turbines achieve the same efficiency with partial loads under 50 % and with cyclic operation as when operating under full load.

Surplus electricity from wind farms and photovoltaic systems can be used to produce hydrogen in order, for example, to mix it with natural gas. The turbines must therefore be able to cope with natural gas with a hydrogen content of at least 10 %.

The ECOFLEX-turbo programme is divided into four disciplines: compression, combustion, cooling and expansion (turbines).

The compressor applies the pressure

In future, compressors will not only have to provide high efficiencies at peak load but also provide stable operation over a wide operational range. To enable turbines to perform a higher number of cycles in future, the damage mechanisms for individual components need to be investigated in more detail. Data forms the basis for better modelling and more powerful simulation programs that enable life-prolonging measures. The goals are shorter development times and more complex geometries, whereby the probabilistic approach is becoming more important. Using this approach, components will be specifically designed for a minimum number of,

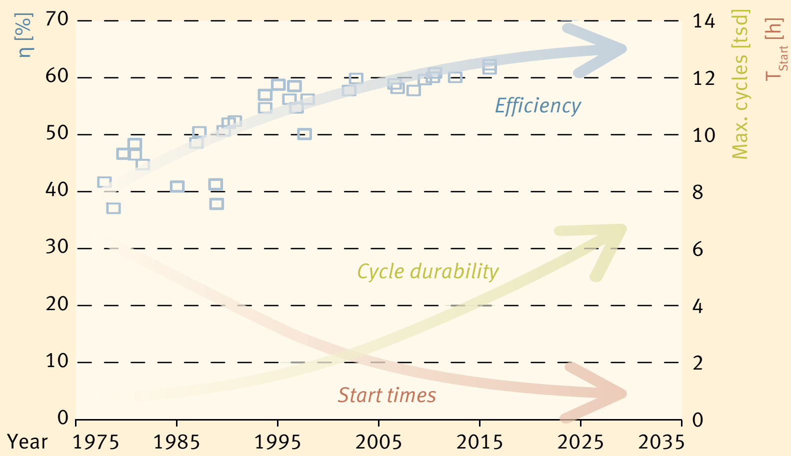

Fig. 1 *Since 1975, the efficiency (η), start times and the maximum cycle durability have improved considerably in power plants with gas and steam turbines (CCPP).*

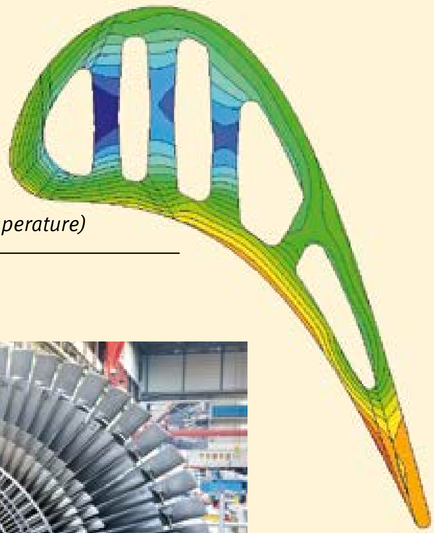

Fig. 2 *Computer model of a turbine blade with the temperature distribution (blue = low temperature, red = high temperature)*

Fig. 3 *A single-chamber industrial steam turbine for power generation with an output of 80 MW*

for example, load and temperature changes based on validated data from models and experiments.

In addition, the researchers would like to predict the actual flow behaviour and increased vibration amplitudes in partial load operation more reliably and also test new possibilities for configuring the flow and vibration damping. This would then enable them to determine and reduce the losses. ECOFLEX-turbo comprises 30 projects in the “Compression” discipline.

Efficient combustion of changing energy carriers

Working under partial load and with more frequent load changes reduces the mass flow of the fuel gas and the efficiency of the combustion in the gas turbine for almost the same temperature in the combustion chamber. Unwanted thermo-acoustic phenomena also occur more frequently. Here combustion vibrations are transferred to the combustion chamber, which leads to premature material fatigue and causes noise. A further stress factor is caused by rapid temperature changes.

The aim of the seven projects in the “Combustion” discipline is to develop a new system for staged combustion and to equip gas turbines with higher reserves against thermal loads and thermo-acoustic phenomena. This is also intended to allow short-term overloading if the turbine is operating

Compression
Cooperation partners*: *MTU Aero Engines AG, RWTH Aachen University, DLR Institute of Propulsion Technology and the University of the Federal Armed Forces.*
Duration: *1 December 2016 – 28 February 2019*

Detailed experimental study of the turbulence and transition behaviour in compressors. For this purpose, highly precise measurements of the turbulence, transition and secondary flow effects are being conducted. The results are intended to increase both the scientific and technical knowledge and lead to improved simulation programs. The investigated phenomena are one of the limiting factors in predicting flows in the partial load range.

Combustion
Cooperation partners*: *Siemens AG, Technical University of Munich, TU Berlin*
Duration: *1 June 2017 – 31 October 2019*

Combustion system for the next generation of gas turbines – liquid fuels. The goal is to require less cooling air and lower the NO_x emissions by means of an improved combustion unit design and a higher number of burners. They are looking to achieve simple fuel injection that distributes the fuel homogeneously over the diameter, achieves short mixing lengths and times and is insensitive to temporal fluctuations of the inflow.

Cooling
Cooperation partners*: *Rolls-Royce Deutschland Ltd. & Co. KG, TU Darmstadt*
Duration: *The project is currently being prepared.*

Aero/thermal testing of blade tip configurations for compact turbines with high power density. As with aircraft turbines, a trend towards smaller, compact turbines can be expected as a result of increased flexibility in the power plant sector. These smaller gas turbines can be deployed more flexibly in combination and can also be used more decentrally. The aerodynamic behaviour of the compact blades and the possibilities for their efficient cooling are being investigated.

Expansion
Cooperation partners*: *MAN Diesel & Turbo SE, Siemens AG, TU Darmstadt, TU Dresden, University of Duisburg-Essen*
Duration: *1 July 2017 – 31 December 2020*

Investigations of heat transfer in steam turbine components. There are three independent areas. The following are being investigated: Variable geometries of turbine side spaces; The correct recording of condensation and evaporation processes in turbine side spaces under wet steam conditions; The heat transfer in real steam turbines with the aim of improving the design of the turbine housing for flexible partial load operation.

Fig. 4 *Characteristic project examples from the four sub-areas*

** Further cooperation partners without project examples:* ***Industrial partners:*** *General Electric* ***Universities:*** *Bochum, Cottbus, Hanover, Karlsruhe, Kassel, Niederrhein, Stuttgart, Trier, Wuppertal, as well as Helmut Schmidt University and Hamburg University of Applied Sciences* ***Technical Universities:*** *Braunschweig, Kaiserslautern* ***Institute:*** *Bundesanstalt für Materialforschung Berlin, DLR Institute of Combustion Technology Stuttgart, DLR Institute of Propulsion Technology in Berlin, Göttingen, Cologne, Fraunhofer Institute Freiburg*

Igniting the turbo

Turbomachines are installed in power plants, airplanes and in pipelines for transporting gases. Their design can be described in a simplified manner using the example of a gas turbine. There are three sections: the compressor (compresses the sucked-in air), the combustion chambers (where the mixture of fuel and air is ignited) and the expansion, also referred to as the turbine (here the hot, over-pressurised gas expands). The gas flows through the consecutively arranged blades, reduces the pressure in doing so and transfers power from the hot gas to the rotating turbomachine. Part of this power (approx. 40-50 %) is required to drive the compressor and the rest is used, for example, in power stations to drive electricity generators. The efficiency of turbines increases with higher pressure in the compressor and a higher temperature when the gas enters the expansion section. Figure 1 shows the development of the performance data since 1985.

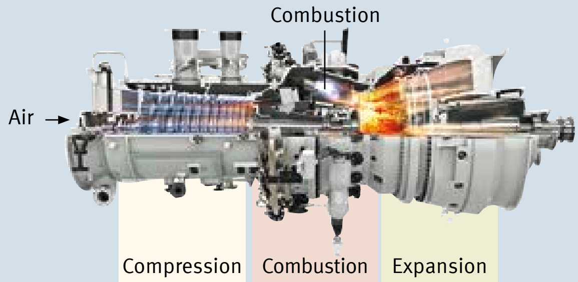

Fig. 5 *Gas turbine with the compression, combustion and expansion sections*

outside its design parameters in order to rapidly stabilise the frequency in the power grid. At the same time, the combustion chambers must be designed in such a way that they function with different gaseous and liquid fuels. In future, it will be particularly important to be able to process fuel gases with a variable hydrogen content. Such an upgraded flexible gas turbine provides a key component for power-to-X concepts.

Cooling: Operation beyond the melting point

Past increases of the turbine inlet temperatures have essentially contributed to today's high turbine efficiencies. Meanwhile, the hot gas temperature is well above the melting point of the highly heat-resistant, metallic materials used for the turbine blades. Ceramic thermal barrier coatings and sophisticated cooling systems for the components allow the temperature resistance. The air flows through the components, passes through gaps and pores, and is laid as a protective film over particularly stressed parts. However, the cooling air requirement reduces the efficiency of the overall system and should therefore be as low as possible.
The 19 research projects in the "Cooling" discipline are, among other things, focussed on a better understanding of the complex flows in the turbine cavities, more effective sealing of the various blade systems and providing better protection of the rotor shaft and bearings against hot gas ingestion. A further approach for optimisation is advanced component manufacturing by direct laser deposition. The 3-D printing process enables more complex and efficient internal component structures to be created for new cooling systems. In addition, the researchers are also investigating the potential improvement offered by components made of ceramic fibre composite materials.

Expansion: Where energy is released

The efficiency of the expansion depends, among other things, on the fact that the hot steam (steam turbine) or the hot gas from the combustion chamber (gas turbine) flows under high pressure as precisely as possible onto the consecutively arranged blade rows. Here the flowing gas is guided in terms of direction and speed by built-in components in the housing and on the shaft. The 38 projects on gas, steam and industrial gas turbines in the "Expansion" discipline are focussing on two aspects: accelerating the development momentum and deploying the new technologies more quickly in existing plants.
For the future grid requirements, it is necessary to achieve a better understanding of the transient processes and the interactions between the flow and components. Other topics are concerned with developing smaller, decentralised turbines for combined heat and power generation. These can be linked with existing municipal and industrial plants and integrated into a smart network. Geothermal and solar thermal power plants also use and require optimised power units.

Turbomachines and power-to-X concepts

By 2050, 80 % of the electricity used in Germany is set to be produced from renewable sources. Conventional power plants with turbomachines will still be needed, however, in order to stabilise the grid and cover periods with low production from renewable power plants. They are also being increasingly used in geothermal and solar thermal power plants. The projects in the ECOFLEX-turbo programme describe the research requirements in order to develop the turbine technology to meet the requirements of the future power grid.

Researchers are already working on new approaches with the power-to-X technologies. These include all procedures for storing temporary renewable electricity surpluses or for converting them into other forms of energy. A well-known example is power-to-gas. Here hydrogen is generated by water electrolysis and then converted into methane by adding carbon dioxide (CO_2). However, turbine research is already concerned with much more far-reaching concepts. The direct use of hydrogen – without the need for using methane – offers significantly higher efficiency.

It is already a development goal to design turbines for natural gas that has been mixed with a higher portion of hydrogen. The long-term goal, however, is to develop turbines that work with pure hydrogen. This would be a step away from an energy provision based on hydrocarbons that releases CO_2 to one based on hydrogen that only emits pure water.

The turbine research forms part of the Flexible Energy Conversion research network, which was founded at the end of February 2017. Here, research institutes and companies from sectors involved in conventional power plant technology, solar thermal power plants and large thermal storage facilities are working together on future strategies. These are aimed at increasing the flexibility of large-scale power plants, developing new large-scale storage systems, extensively researching the use of hydrogen in power plant processes and, in particular, optimising the economic efficiency of solar power plants. Prospects for higher energy efficiency are also provided by improving the sectoral coupling of conventional power plants with the transport sector or the chemical industry with the aim of producing synthetic fuels and chemical base materials. The seventh research network, focussing on flexible energy conversion, has now started it's work. This complements the already existing networks for buildings and districts, system analysis, electricity networks, renewable energies, biomass as well as industry and commerce.

Project participants

- **Programme coordination:** AG Turbo, Scientific Coordination Office: German Aerospace Center (DLR), Cologne, Sabrina Costantini, sabrina.costantini@dlr.de

Links (in German)

- www.ag-turbo.de
- https://www.forschungsnetzwerke-energie.de/flexible-energieumwandlung
- http://kraftwerkforschung.info/en/

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