

EMRP Project ENG06 Powerplants : Metrology for Improved Power Plant Efficiency

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Abstract – Large scale power plants based on nuclear or conventional fuel provide about 80 % of generated electricity in the EU and nearly 90 % of hot water used for district heating. As electric energy cannot be stored in significant amounts it has to be generated at the time of use. Consequently, a mix of basic, medium and peak load power plants is necessary in order to balance consumption and production. Despite the necessity of renewable energy, large scale power plants will form the backbone for the secure supply of energy for the next few decades. It is therefore of outstanding importance to increase the energy efficiency of such power plants.

The EMRP Joint Research Project ENG06 Powerplants focuses both on the metrological research necessary to reduce the measurement uncertainty of important control parameters (temperature, flow, thermal energy and electrical output) of power plants and on research on advanced materials to be used in future turbines. The total results of the research work could lead to an overall additional enhancement of energy efficiency of 2 % - 3 % for all types of large power plants, and a commensurate reduction of emissions.

In Europe steam power plants are an important source of electricity generation and whilst a considerable number of them are due for replacement during the next decade, even with anticipated increased use of renewable energy sources, it is generally expected that in 2020 around 40 % of electricity will still be produced by conventional power plants. The average efficiency of steam power plants across Europe is 36 %, and up to 46 % for the most modern ones. By increasing the steam temperature of the next-generation power plants from the current 540 - 600 °C to 700 °C an improvement in efficiency to around 50 % is possible, resulting in CO₂ reductions per MWh of generated electricity of about 25 %. To increase the efficiency of gas

turbines to above 60 % an increase of the typical gas inlet temperature from currently 1300 °C to 1500 °C is necessary. And globally, the situation is even more demanding as the mean efficiency of coal power plants is of around 30 %.

Improving the efficiency of conventional power plants raises a number of significant metrological challenges, which are addressed in this European Metrology Research Project in four dedicated work packages:

WP1 Temperature measurement

Thermometers used in power plants or in thermal energy distribution networks cannot be calibrated in a calibration laboratory under the same harsh conditions as during operation. This workpackage aims to investigate the major sources of uncertainty and drift of industrial resistance thermometers for the next generation of steam power plants (700 °C) and to characterise the immersion behaviour and the vibration-resistance of suitable platinum resistance thermometers. With the aim that stability will be improved to 1 K/year.

In the field of non-contact the objective is to develop method for surface temperature measurements of turbine blades (up to 1500 °C) based on radiation thermometry, including a methodology for in-situ calibrations by means of MC eutectic fixed points.

For a future hard coal power plant the requirements to the control system will be 5 % - 7 % power change within one minute for the secondary load control and up to 10 % within 10 s for the primary control. This requires considerable effort to optimise the positioning, contacting and the dynamic behaviour of the temperature sensors. A further aim is an optimised dynamic “two-shifting” behaviour of a power plant in order to compensate for power-grid loads. These grid loads are caused by both consumer behaviour as well as the increasing amount of power generation by renewable energy sources, e.g. wind or

solar energy, which makes the power output inevitably dependant on weather conditions.

WP2 Thermophysical property measurement

Increasing steam and gas temperatures require novel materials with improved durability to thermal load and corrosion. For turbine blades, corrosion resistance and thermal barrier coatings are essential for operation at temperatures up to 720 °C and water vapour pressures of about 35 MPa in steam power plants. To improve the efficiency of gas turbines to above 60 % requires an increase of the typical gas inlet temperature from currently 1300 °C to 1500 °C, which sets high demands on the thermal barrier coatings (TBC), as this temperature is often close to the melting temperature of the base material. However, in this temperature range improved measurement techniques are required to investigate flue gas corrosion and the high-temperature oxidation behaviour for Ni-based alloys to predict their behaviour for working lifetimes of upto several 100 000 hours. In addition the measurement of emissivity, which governs the radiative heat exchange with the environment, is exceedingly challenging at elevated temperatures. Therefore, accurate reference facilities and methods for the measurement of thermal properties of homogeneous solid materials and TBCs at high temperature (up to 1500 °C) will be developed and the thermophysical properties of Ni-base alloys or/and TBCs specimens under temperature conditions encountered in gas turbines will be investigated.

WP3 Flow & thermal energy

Energy flow normally equates to fluid flow at some point. Energy is generated by steam, transported as hydrocarbon fluid and consumed through heating and cooling fluids. Measurements are required within industry to quantify inefficiencies, measure improvements and to meet regulation. These measurements need to be carried out at extremes of viscosity, temperature, pressure, and on multiphase and multi component mixtures. Conditions are often outside the scope of conventional techniques and sensors. Measurement of energy flow has to encompass novel integration of sensors for flow, temperature, pressure, composition and fluid parameters operating in field and industrial conditions at economic cost. The lack of precise flow rate measurements currently limits the efficiency of power plants and thermal energy distribution networks. For example, to fulfil safety regulations in nuclear power plants the permitted thermal power output is reduced to a value 2 % below the nominal maximum power to account for the uncertainty of 2 % of the flow rate measurements. Reducing the flow rate measurement uncertainties to 0.5 % would directly enhance the power output by the same amount. Additionally, for all types of power plants the uncertainties in flow rate measurements lead to non-perfect steering and control mechanisms. Recent studies indicate that efficiency enhancement due to optimised control and operation modes based on precise flow rate measurements sum up to an efficiency gain of approximately 2 %.

Flow meters used in power plants or in thermal energy distribution networks are not and cannot be calibrated directly, as the harsh operation conditions (e.g. flow-rates up to 5000 m³/h, temperatures at least 280 °C to above 1500 °C, pressures up to 20 MPa) are and will not be realised in any calibration laboratory in the world. The challenge lies in establishing metrological sound and accepted models of the influence of process conditions on flow metering with the aim to reduce the uncertainty of flow metering from around 2 % to approx. 0.5 %.

WP4 On-site electrical power output measurement

A final need relates to the actual determination of the effect of all measures taken to increase the efficiency of power plants via on-site measurements of the electrical power output of the plants, particularly the dynamic measurements necessary to balance variable net load due to the discontinuous nature of renewable energy sources (wind and solar). Therefore this workpackage aims to develop means for fast, reliable and traceable on-site measurements of the electrical output of power plants up to 200 MW at high voltage (100 kV) with an uncertainty of better than 0.1 %.

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