SURFACE TEMPERATURE MAPPING OF GAS TURBINE BLADING BY MEANS OF HIGH RESOLUTION PYROMETRY

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Introduction

For more than a decade Siemens has been using optical pyrometry[1,2,3] for the testing of its gas turbine prototypes in the Berlin test bed[3]. The main objective is the experimental evaluation of both standard and prototype blade designs under real base load conditions. Furthermore, pyrometry is a valuable tool for the quality assurance, since the temperature distribution of each individual blade is determined carefully. This paper describes the application of a newly developed high resolution pyrometer[4] to the latest prototype, the V84.3A2 60Hz 180MW gas turbine[5]. A pragmatic approach to the different sources of error, such as flame radiation, limited resolution or exceeded incidence angle will be discussed in more detail.

System Setup

Figure 1 shows a schematic of the system used: a host PC controls both the traversing unit for radial and rotational movement of the cylindrical probe as well as the “satellite” PC for data acquisition, that is positioned adjacent to the gas turbine. The temperature data is transferred via ethernet to the host PC in the remotely located control room. The system is fully automated and up to four satellite PC and pyrometer probes can be operated at the same time. Alternatively, probes which are equipped with thermocouples may be used in order to determine the radial gas temperature profile. The single wavelength spectral band pyrometer (λ = 0.85 µm) has a minimum field of view of 1mm and a temporal resolution of 1 µs.

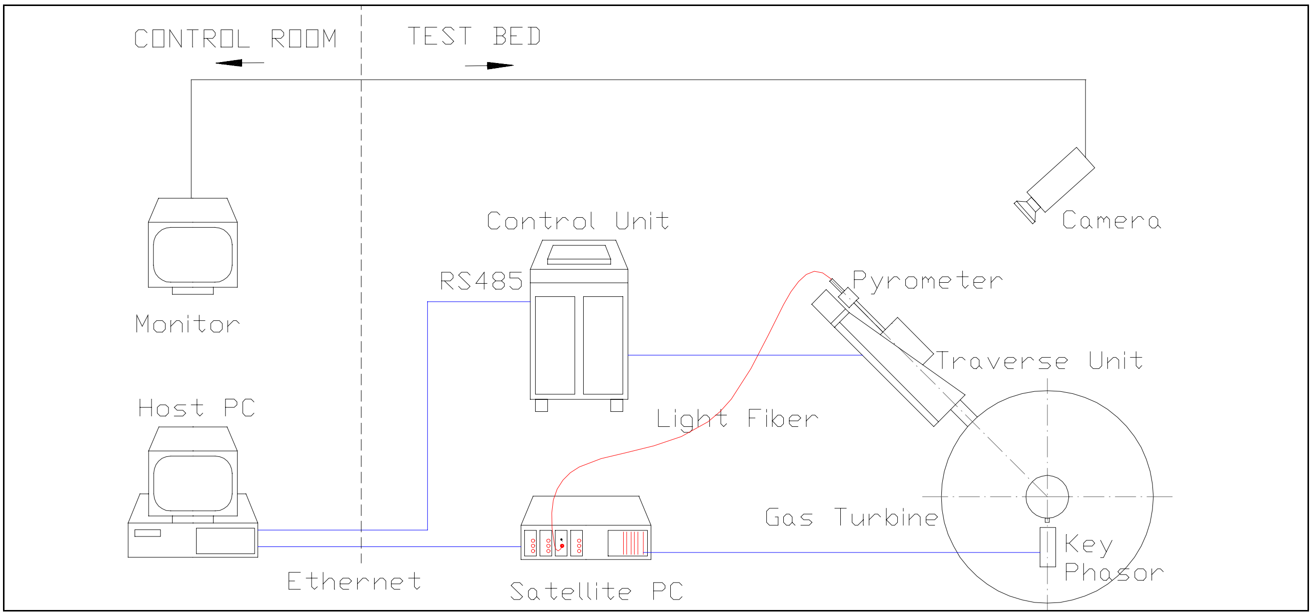

Figure 1: schematic of the pyrometer system

With regard to the uncertainty of measurement, traversable probes have one important advantage over non-intrusive methods: the spatial resolution is equally small for each data point of the blade regardless of traverse depth, whereas the effective field of view for non-intrusive scanning pyrometers increases with insertion depth. Furthermore, the intrusive type pyrometer allows the viewing angle to be changed, hence, different zones of the blade may be scanned at an acceptable incidence angle and with a minimum field of view. Thus, in the test bed, surface temperature mapping is performed in two different ways:

- discrete blade measurement, i.e. the probe is traversed at a certain radius and viewing angle before blade data is acquired, subsequently radius and viewing angle may be changed
- continuous blade measurement, i.e. the probe is traversed slowly from the tip to the hub, e.g. with 2mm/revolution, and data is acquired continuously; subsequently the pyrometer is withdrawn and the process is repeated for another viewing angle

The main disadvantage of the intrusive mode, however, is the potential risk for the gas turbine and the pyrometer itself: the latter is highly loaded by thermo-mechanical stress, whereas the former is jeopardized by vibration problems, due to the blockage of the flow channel between two vanes when the probe is fully inserted. In order to overcome this problem continuous blade measurements are preferred. Hence, the necessary time for measurement and thus for vibration excitement of the turbine is minimized. In a period of not more than one or two seconds, the whole blade surface is mapped at maximum resolution, thus providing some five thousand different data points per blade and viewing angle.

Experimental Results

Optical pyrometry has been used for various measurements of the first stage vanes and blades under design conditions, i.e. at base load. The V84.3A2 gas turbine is equipped with an annular ring combustor that is suitable for different fuels such as natural gas and fuel oil. Flame radiation of the combustor is directly emitted onto the blading; it is one of the major problems for pyrometer measurements in the first stage. Statistical evaluation of discrete blade measurements allows for the assessment of random errors and provides the following results: the standard deviation of temperature at a certain point on a particular blade for a given set of e.g. ten revolutions amounts to about 0.2% for fuel oil and natural gas. However, the average blade temperature is slightly higher for fuel oil than it is for natural gas at the same gas turbine inlet temperature. Figure 2 displays the temperature distribution of one particular prototype blade for different operating and measuring conditions. The left-hand distribution has been determined by means of a commercial pyrometer using fuel oil premix mode and discrete blade measurements, while on the right the distribution is shown as determined by high resolution pyrometry in conjunction with continuous blade measurements using natural gas. Obviously, Figure 2b provides a much more detailed thermal image than figure 2a. This is mainly due to the radiation emitted by oil flames, and only partly a matter of pyrometer resolution. However, in order to detect very small structures such as film cooling holes, high resolution pyrometry has to be applied.

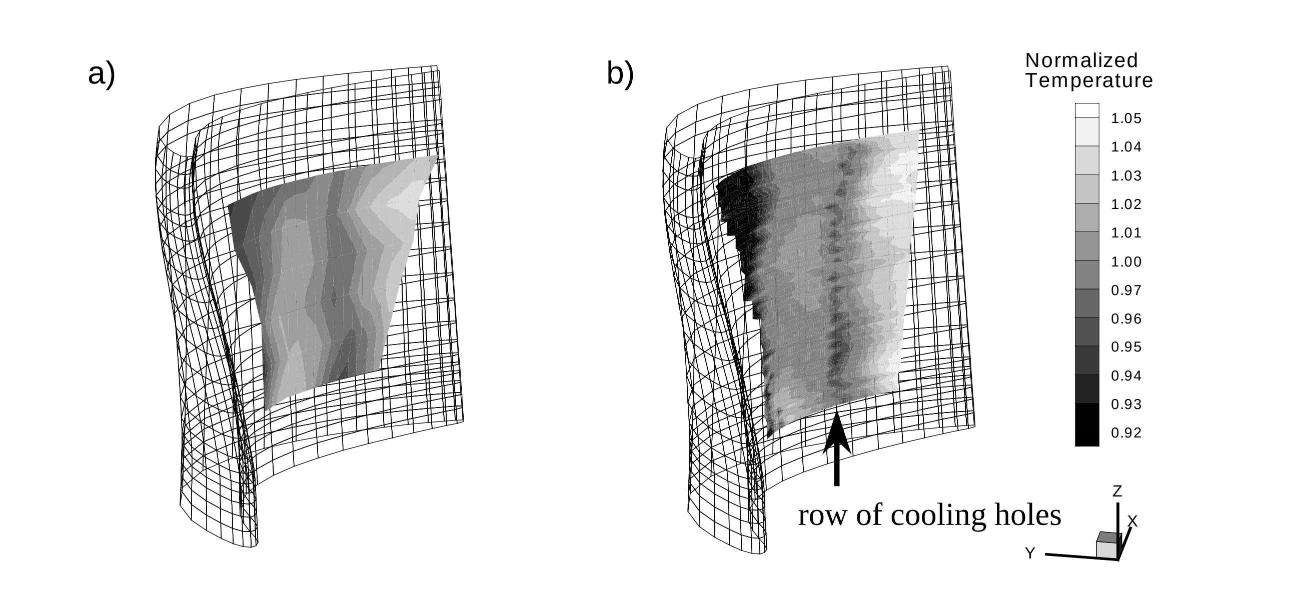

Figure 2: Temperature distribution (almost axial viewing angle) of the same first stage prototype blade under different test conditions, but constant turbine inlet temperature

a) fuel oil diffusion mode, commercial pyrometer (min. field of view 3mm, sample frequency 100kHz), discrete measurements, i.e. six radii with 20 data points each

b) natural gas premix mode, high resolution pyrometer (min. field of view 1mm, sample frequency 500kHz), continuous measurement, i.e.50 radii with 100 data points each

Conclusions

Taking into account the latest test results it can be concluded that

- Pyrometer measurements in the presence of natural gas flame radiation yield reasonable results, whereas for fuel oil a suitable flame radiation correction is strongly recommended
- No averaging is necessary since the standard deviation is very low, i.e. any of a set of several revolutions is representative for the actual temperature distribution
- Using high resolution pyrometry even smallest structures such as single film cooling holes can be easily detected in the thermal image of the blade

Thus, using new pyrometer probes in conjunction with a continuous data acquisition mode allows reliable, highly resolved blade surface temperature measurements, where errors and potential risks for the gas turbine are minimized at the same time.

References

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