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HEALTH & SAFETY LABORATORY

Outstanding safety questions concerning the analysis of ventilation and gas dispersion in gas turbine enclosures:

Best Practice Guidelines on in-situ testing

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EXECUTIVE SUMMARY

The aim of this document is to provide practical guidance on in-situ testing for ventilation/dispersion in gas turbine (GT) enclosures. The guidance draws on, and is consistent with, HSE Guidance note PM84[(1)], '*Control of safety risks at gas turbines used for power generation*'.

The guidance has been produced with assistance from a number of companies and individuals active in the area of in-situ testing. Their input is gratefully received and acknowledged, and detailed above.

Main Recommendations

It is unlikely that measurements or Computational Fluid Dynamics (CFD) analysis alone can demonstrate effective dilution ventilation within a gas turbine enclosure. However, field measurements conducted on actual enclosures are useful for indicating flow patterns, identifying poorly ventilated areas and, assessing the performance of the enclosure's ventilation system. Measurements also have a key role to play in supporting and validating CFD simulations.

Airflow and temperature should be measured at a range of locations throughout the enclosure to effectively map the airflow movement. Ideally, airflow and temperature should both be measured at the same location. The number of locations measured will depend on the complexity of both the GT enclosure and of the modelling with which they will be compared.

As it is unlikely that the flow direction inside the GT enclosure will be known, omnidirectional probes are the preferred transducer for measuring air speed. If a directional device is to be used e.g. Vane or slotted thermal anemometer, the flow direction should be evaluated at each position before a measurement is made.

The presence of the operator may have a large impact on the accuracy of any measurements, particularly those of velocity, but also of temperature. Where practical therefore, it is recommended that remote transducers be used. This also removes the need for the operator to remain inside the enclosure when the GT is running. Where remote measuring is not practical, efforts should be made to ensure that the influence of the measurer is minimal.

It is recognised that there may be a limited amount of time in which in-situ measurements can be made. Therefore a compromise may need to be reached between accuracy and the number of measurements required. It is unlikely that fewer than 10 or so measurements will give sufficient information, but it is also unlikely that comparisons with 100 or so measurements would be practical.

Ideally, measurement of air speeds inside the enclosure should be made both (i) when the turbine is offline with the ventilation on, and (ii) with the turbine at base load. In practice, it may not be practical nor safe for personnel to be inside the enclosure when the turbine is running.

For temperature measurement, the preferred instruments are K-Type (Chromel-Alumel) thermocouples, which are readily obtained and relatively inexpensive. IR thermal photometry should also be considered where additional information could be used for operational purposes, or for other purposes such as demonstrating that specified surface temperatures were not being exceeded at any point, or to define surface temperatures to be used as CFD boundary conditions.

Surface temperatures are unlikely to be modelled in detail, but it is important to obtain between 5 and 10 measurements at different points for each discreet area that is being considered in order that reasonable average values can be produced.

Volume flow rates and temperature conditions at the air inlet(s) and exhaust point(s) will be required for any overall energy and mass balances.

Once the GT ventilation system is operating satisfactorily, static pressure measurements, carried out at regular intervals, are a useful method of monitoring the system performance. Possible measurement positions include; inlet to the fan, in the duct work close to the inlet(s) and outlet(s) to the GT enclosure and a reading of the pressure inside the enclosure.

When recording data measurements it is good practice to make sure the data is repeatable and reliable. Instruments should be calibrated and ideally traceable to national standards.

1 INTRODUCTION – AIMS AND SCOPE OF THE GUIDANCE

The aim of this document is to provide practical guidance on in-situ testing for ventilation/dispersion in gas turbine (GT) enclosures. The guidance draws on, and is consistent with, HSE Guidance note PM84[(1)], '*Control of safety risks at gas turbines used for power generation*'.

The guidance identifies generic types of instrumentation that are deemed appropriate for use during in-situ testing of GTs. Capabilities and limitations of instrumentation are discussed, along with measurement techniques. However, these should not be considered exhaustive, as the design of the GT will influence the choice.

Field measurements conducted on actual enclosures are useful for indicating flow patterns, identifying poorly ventilated areas and, assessing the performance of the enclosure's ventilation system. However, it is unlikely that measurements or Computational Fluid Dynamics (CFD) analysis alone can demonstrate effective ventilation. Consequently, measurements are often used in conjunction with CFD, in particular to supply boundary conditions for a CFD model and data to allow validation of a model. This guidance reflects this situation and includes information on the measurements that CFD modellers require. Further guidance on CFD Best Practices can be found in Ivings et al[(2)] (2004).

The guidance has been produced with assistance from a number of companies and individuals active in the area of in-situ testing. Their input is gratefully received and acknowledged, and detailed above.

W S Atkins Consultants and GE Power Systems have supplied a method statement for in-situ tests in GT enclosures. It has been specifically drafted and is based on field experience of these companies. The present guidance draws on and largely reflects the contents of this method statement.

2 AIMS OF IN-SITU TESTING FOR VENTILATION/DISPERSION IN GAS TURBINE ENCLOSURES

2.1 ASSESSMENT OF VENTILATION

A well-designed dilution ventilation system will not only assist with the cooling of GTs but should also act as a safety feature to prevent buildup of flammable mixtures. HSE guidance note PM84(1) states that the preferred method of ventilation is by dilution. This is achieved by rapidly mixing any gas leak with the main body of air in the enclosure to produce concentrations well below flammable limits. The resultant mixture should be transported out of the enclosure before a build up in concentrations can occur. To be effective dilution ventilation should therefore also ensure that there are no stagnant, poorly ventilated spaces, and no recirculation zones. This may require a number of air inlet/outlet positions and in extreme cases mixing can be improved by the use of supplementary fans or distributors. It is important to measure the volume flow rate through the GT enclosure to ensure the design flow rate is being achieved. However, it should be noted that the ventilation rate provides no information on the detailed movement of air inside the enclosure, and therefore proves limited data on the effectiveness of the ventilation. Therefore, the distribution of the air can be more important that its quantity and should be considered as part of any assessment of the ventilation.

It is advisable to assess the ventilation effectiveness under both normal operating conditions and cold start-up. This is particularly important if the ventilation flow is likely to be strongly influenced by thermally driven convection currents, which will be absent at cold start-up. However, it is appreciated that the number and type of measurements taken inside the enclosure when the turbine is at base load may be limited due to safety reasons.

2.2 DEMONSTRATION OF VENTILATION EFFECTIVENESS

To fully demonstrate the effectiveness of ventilation within an enclosure would require a large number of velocity measurements distributed throughout the enclosure. However, the presence of a gas leak can locally modify the ventilation flow and this effect is difficult, and often impractical to reproduce experimentally. Nevertheless, measurements have a key role to play. For example, velocity measurements, when combined with flow visualisation, are useful for indicating flow patterns and identifying poorly ventilated areas. Measured data should therefore also be used to support and validate CFD simulations.

Once the ventilation effectiveness has been demonstrated, air speed and pressure measurements at key positions in the system should be carried out on a regular basis to ensure acceptable ventilation performance is maintained. Measurements would need to be made both within the enclosure and in the associated ventilation ductwork.

2.3 PROVISION OF DATA FOR CFD MODEL SET-UP AND VALIDATION

Experimental data should be used for both setting realistic CFD boundary conditions and during the model validation process. Measurements used to set boundary conditions should characterise the airflow and would need to include measurement of volume flow rate, air temperature and velocity at all GT inlets and outlets. If required, the velocity profile at inlet(s) and outlet(s) should be measured. Surface temperatures at a number of positions inside the GT would be required, for example on the walls of the enclosure, on the floor and along the turbine casing. Ideally, these measurements would be carried out when (i) the turbine is offline, the ventilation active and the enclosure cold and (ii) the turbine is at base load.

Data from experimental measurements used during the CFD validation process would include spot measurements of air velocity and temperature at a number of positions within the enclosure. Ideally, as many measurements as reasonably practical should be made, ensuring as a minimum that measurements are made at key positions identified within the enclosure. Measurements can also be used to confirm that any design changes have had the desired effect. Flow visualisation tests are also useful to compare with the CFD predictions during the model validation stage.

Although somewhat outside the scope of this guidance, a video or photographic record of the inside of the enclosure is useful when generating a CFD model.

3 MEASUREMENT METHODS: CAPABILITIES AND LIMITATIONS

3.1 SMOKE TESTS

Artificial smoke is often used to visualise the movement of air in a space. The tests themselves are relatively easy to carry out and are useful for checking air movement, air direction and for identifying stagnant areas. Smoke visualisation tests are particularly valuable during the validation stage of CFD models. It can also be useful to video smoke visualisation tests for later analysis. However, it is generally a qualitative method and as such, the results are subjective. For that reason, smoke tests should only be used to draw broad conclusions on the overall performance of a ventilation system and therefore such tests cannot demonstrate dilution ventilation.

Leakage paths into, or possibly out of, the enclosure could influence flows inside. Smoke tubes can be helpful in indicating leakage paths and flow direction, but quantification of individual leakage rates by any of the means outlined in this section is difficult unless the leakage path is very well defined.

It is unlikely that the temperature of the ambient air and the emitted smoke will be the same. There may therefore be initial density effects, which would need to be considered.

There are a number of methods for generating artificial smoke. For generating relatively small amounts, smoke tubes are probably the easiest method and are widely used. However, the smoke is corrosive and an irritant and therefore should be used with care. If large amounts of smoke were required, a smoke generator would probably be most suitable. These vaporise a liquid (usually mineral oil or glycol and water) that condenses into a fine aerosol on contact with cooler air. The generators can produce a large amount of smoke over a long period and the amount of smoke produced is controllable.

Artificial smoke will break down as the ambient temperature rises. Water-based smokes are usable in environments with air temperatures up to about 60^{o}C. For higher temperatures oil based smoke should be considered, as these can be resistant to temperatures up to 180^{o}C. However, the Material Safety Data Sheet should be consulted before liquid is used for generating artificial smoke. Additional lighting may be required to visualise the smoke and to therefore highlight the airflow structure.

3.2 AIR SPEED MEASUREMENT

3.2.1 Introduction

The airflow patterns encountered in a GT enclosure will be turbulent and are likely to be highly three dimensional. Therefore, measurement errors will almost certainly be larger than would be expected in laboratory conditions. To obtain accurate readings, the air speed measured at a point within the enclosure should be averaged over sufficient time. This would typically be of the order of one to two minutes, but will be dependent upon the measuring position in the flow field.

There are many different types of instruments available that measure the speed of the air at a point, and it is important to select the most suitable instrument for the particular task in hand. The instrument should be capable of measuring over the range required and to the required accuracy. In particular, measurements should not be made below the minimum air speed quoted in the instrument handbook.

Information is given below on the different types of instrument that are deemed suitable for making in-situ measurements.

3.2.2 Pitot static tube

This instrument consists of two concentric tubes. The inner tube has a front opening, which is pointed into the flow. The outer tube has annular openings at right angles to the airflow. By connecting a pressure gauge across the tubes, the velocity, or dynamic, pressure of the air stream can be measured, and from this the air speed calculated.

A standard Pitot static tube is simple, inexpensive, and durable. It does not require calibration and, using a reasonably priced pressure gauge, is suitable for measurements above 3 ms^{-1}. Measurements at lower air speeds can be made if a more accurate digital micromanometer is used. For accurate measurements, Pitot static tubes should be aligned with the airflow and as such are usually only used to measure velocities in ducts or other structures where the flow direction is well defined. The gauge used to measure the pressure should be calibrated; noting that the calibration of some pressure gauges can drift if used at high ambient temperatures.

If conditions differ from standard pressure and temperature (1013 mbar and 20^{o}C), corrections should be made to account for the change of air density.

3.2.3 Thermal anemometers

Many commercial thermal anemometers have small diameter probes. In order to minimise the risk of physical damage to the transducer, it is often mounted in a protective shroud with an open slot at the end of the probe. To minimise errors, this slot should be aligned with the flow direction.

Thermal anemometers are typically not suitable for measuring air speeds below 0.2 ms^{-1}, although the more expensive instruments can measure lower. The maximum measurable air speed is also usually dependent on the price of the instrument and varies from 10 ms^{-1} up to 70 ms^{-1}. Most thermal anemometers now incorporate simultaneous measurement of both air speed and temperature, allowing air temperatures to be measured to within ±1ºC. This level of accuracy is more than adequate for in-situ measurements.

Thermal anemometers give no information on the flow direction and to minimise errors they must be orientated such that the slot is aligned with the airflow. If flow direction is not known, omnidirectional probes should be considered. These devices have a spherical bead transducer and tend to be more accurate at low air speeds, but often have a smaller measurement range. These instruments usually give air temperature information and often include a measure of turbulence intensity of the airflow.

3.2.4 Vane anemometers

These anemometers measure the average air speed over the area of the vane and tend to have larger sensing heads than the thermal devices, typical vane diameters range from 15 mm to 100 mm. Again, to reduce errors, they must be aligned with the airflow. Whilst vane anemometers tend to be virtually unaffected by pressure and temperature, they are not suitable for measuring air speeds below 0.25 ms^{-1}.

3.2.5 Ultrasonic anemometers

These instruments tend to measure lower air speeds with a higher accuracy than both the thermal and vane anemometers. As long as the sensors are not damaged, manufacturers claim they require no calibration. Nevertheless, obtaining a certificate of conformity from the manufacturer is advisable. Dependent on the instrument design, some ultrasonic anemometers measure all three components of the airflow, thus giving information on both the magnitude and the direction of the airflow. These types of ultrasonic anemometers do not need to be aligned with the airflow. However, these instruments are more expensive and tend to be larger than most anemometers and consequently have a larger measuring volume. Additional data logging equipment may also be required.

3.2.6 Suitable instruments for measuring air speed within the GT enclosure

Thermal anemometers are suitable for measuring air speeds within a GT enclosure. If the sensor is mounted in a slot it should be aligned with the airflow. Smoke visualisation may be useful for evaluating flow direction at the measurement position before measurements are made. Alternatively, a ‘tell tale’ (e.g. a fine length of cotton) can be used to evaluate the flow direction. If the direction of the air at a point is not known, an anemometer that has an omnidirectional probe should be considered.

As the sensors tend to be small, the instruments are able to measure the air speed at a ‘point’. However, any strong gradients present in the flow field could lead to a misrepresentation of the airflow. This can be addressed by averaging over a number of measurements taken at slightly different positions. Unsteadiness in the flow field can also be evaluated by repeating measurements at key positions. Deviations between these measurements may indicate an unsteady flow.

Thermal anemometers will only give accurate measurements for a finite range of air temperatures. The manufacturer of the instrument will specify this range. Care should be taken to ensure that the instrument selected is capable of operating at the air temperatures encountered inside the GT enclosure at the required accuracy.

Caution should be exercised when measuring close to a hot surface, as radiant heat will reduce the heat loss from the probe. This will manifest itself as a variable error. Shielding of the probe could be considered, so long as this does not affect the airflow patterns at the measuring position.

Vane anemometers may also be used, but again the flow direction needs to be known so the probe can be correctly orientated. Again, smoke visualisation would be useful for evaluating flow direction at the measurement position before measurements are made. As vane anemometers average the air speed over an area, a degree of spatial averaging is given and therefore they are not as susceptible as thermal anemometers to probe location errors. It should be noted, however, that the minimum air speed capable of being accurately measured with these instruments tends to be higher than those of the thermal devices.

Both thermal and vane anemometers are available as hand held instruments. As such they are relatively cheap, easy to use, and require no set-up time. Remote transducers are available but are likely to require a data logging system. The advantage of the latter is that personnel do not have to be present inside the enclosure during measurements, thereby eliminating any effects of the operator on the flow field.

If the air speed is required along with an accurate measure of flow direction, then ultrasonic anemometers are probably the most appropriate instrument. These instruments can often be networked to allow a number of positions to be measured simultaneously. This usually requires a laptop computer. The instrument is larger than a vane or a thermal anemometer and measures the velocity of the air over a defined volume rather than at a 'point'. Whilst this has the advantage of minimising probe location errors, ultrasonic anemometers are relatively large and therefore may present a problem in heavily congested areas.

Assuming that the flow patterns in an enclosure do not vary with time, and a reasonable number of velocity measurements are made, a picture of the overall flow field throughout the volume of the enclosure can be created. If it is not practical to make a large number of measurements inside the enclosure, then key measurement positions should be identified. Experienced staff will be required for this task.

3.2.7 Suitable instruments for measuring GT ventilation volumetric flow rate

The internationally accepted method of accurately establishing the airflow rate in a ventilation system is by measurement of velocity at representative points across the entire cross section of a duct. The most common instrument used is a Pitot static tube connected to a pressure sensing device. However, thermal anemometers may also be used. Ideally, measurements should be made in a straight section of duct well away from obstructions. As a guide, the measuring position should be at least seven diameters (or equivalent) downstream of any bend or flow obstruction and not less than one diameter (or equivalent) upstream of similar obstructions. The velocity profile across the duct will not be uniform, therefore the recommended number of measurement traverses and measuring positions should be used (BS1042, Part 2.1[(3)]). Multiplying the mean velocity by the cross sectional area of the duct will give the volume flow rate. Ideally, measurement of volume flow rate should be carried out both with the turbine offline and at base load.

If a suitable straight section of ductwork cannot be located or is not accessible, accurate measurement of the volume flow rate may still be possible if more duct traverses are carried out. Alternatively, the volume flow rate can be calculated from air speed measurement made at the air inlet(s) and outlet(s), although errors in readings may be appreciably larger.

If smoke tests have identified the presence of significant leakage paths through the walls of the GT enclosure, then an approximate measure of the volume flow rate through these paths may be possible. The accuracy of the measurement will depend upon the geometry of the gap. Thermal anemometers are probably most suited for such measurements. However, if the width of a gap is similar to the width of the probe, errors will be large and measurement should be used for indication only.

3.3 TEMPERATURE MEASUREMENT

3.3.1 Introduction

Ideally, both air and surface temperature measurements should be made in the GT enclosures both with the GT offline and at base load. Measurement of the surface temperature of the turbine casing, enclosure walls, floor should be made. Measurement of air temperature should be made at the air inlet(s) and outlet(s) as well as a number of positions inside the enclosure.

3.3.2 Surface temperature

Surface temperatures may be measured using surface contact probes. Thermocouples are well suited for this task, being, robust, stable and accurate, allowing surface temperatures to be measured to within ±1ºC, which is more than adequate for in-situ measurements. Thermocouples measure the difference in temperature between the “hot junction” (usually the tip of the instrument) and the “cold junction” (usually at the readout/logger). Typically, there will be an absolute measurement of temperature at the “cold junction”, most often using a resistance thermometer, which is added automatically to the temperature difference to give a reading of the absolute temperature at the tip.

If a thermocouple readout or logging system is positioned inside the hot enclosure, it is important that a sufficient period of time is given to ensure that the “cold junction” and the reference temperature measurement are actually at the same temperature. The time required for this will vary with the readout design, but may be several minutes. If it were possible to take the instrument cables out of the enclosure without compromising the internal flows then it would be preferable to have the readout/logger outside the enclosure.

Alternatively, infrared thermometers can be used for non-contact measurements, although these require knowledge of the surface emissivity. This is often obtained either by applying a thin layer of highly emissive paint to the particular measurement spots, or by making an independent measurement of the surface temperature at a number of points on each type of surface to “calibrate” the IR measurements. These systems have the advantage of providing a detailed overall picture of surface temperatures, allowing particular “hot spots” or cooler areas to be easily identified. Infrared measurements can also be made in a relatively short time. However, additional time is needed once the measurements have been made to interpret the IR record. Furthermore, the equipment is larger and more difficult to handle than surface probes, and so may not be able to cover all the hot surfaces in a confined GT enclosure.

3.3.3 Air temperature

Measurement of air temperatures can also be made using thermocouples with a similar accuracy to those of surface temperatures. There are a number of different types of thermocouples available; many of them would be suitable. However, it is important that air temperature instruments, particularly those used in measurements close to hot surfaces, are shielded from the effects of thermal radiation.

If the readout/logger was outside the enclosure then an “array” of thermocouples could be used. The thermocouples could be mounted at different heights on a mast, or pole. This can be placed at a known point on the enclosure floor, and measurements made simultaneously or sequentially from outside. This arrangement would minimise the effect of personnel and the instrumentation on the temperatures being measured. However, it may also increase the cost of carrying out the measurements, particularly for surface temperatures.

With spot measurements, such as those obtained with contact thermocouples, accurate location of the measuring points can be difficult unless time is taken for each measurement. Repeated measurements with one probe at various locations, or the placement of a number of probes for simultaneous measurement can be time consuming, which will have cost implications and may have safety implications. The technique of manual point measurements may be combined with video recording to allow later analysis of exactly where the measurements were taken, if high positional accuracy is needed.

However, in most CFD modelling, the hot surfaces are taken to be at a uniform temperature (or possibly in two or three sections with different uniform temperatures if some parts are significantly hotter or cooler). Because of this, precise location of the measuring points may not be necessary, and the important factor is to take a number of measurements that can be used to provide average temperatures.

Each of these manual techniques require staff to be inside the GT enclosure while the measurements are made. This may have an effect on the airflows, and hence change the distribution of heat within the enclosure. This is likely to be more significant for air temperature measurements, and less so for surface temperatures.

3.4 STATIC PRESSURE MEASUREMENTS

Whilst it is unlikely that CFD modellers would require data from static pressure measurements, they are useful for monitoring the consistency of performance of a GT ventilation system. Initially, static pressure measurements would need to be made to establish baseline data when the ventilation is operating satisfactory. These should be carried out with the turbine both offline and at base load. Measurement of the volume flow rate, together with static pressure measurements, can then form the basis of a performance check, which could be carried out at regular intervals. Assuming no modifications have been made to the GT, the enclosure and associated equipment, any deviation from baseline data may indicate a change in ventilation performance.

Possible measurement positions include; inlet to the fan, in the duct work close to the inlet(s) and outlet(s) to the GT enclosure and a reading of the pressure inside the enclosure.

It is possible to measure static pressure using a pressure gauge connected to a Pitot static tube or a wall probe.

3.5 CALIBRATION

Most instruments will require regular calibration checks, ideally traceable to national standards, to ensure measured data is accurate. The instrument manufacturer should be consulted as to the frequency of calibration.

4 RECOMMENDATIONS

Many instruments available today are designed to be hand held. Nevertheless, proximity of the operator can affect the accuracy of the measurements. To minimise this, instruments often have extendable probes. However, flow patterns inside a GT enclosure are likely to be complex and highly three dimensional and the presence of the operator may have a large impact on the accuracy of any measurements, particularly those of velocity, but also of temperature. Where practical therefore, it is recommended that remote transducers be used. This also removes the need for the operator to remain inside the enclosure when the GT is running. Where remote measuring is not practical, efforts should be made to ensure that the influence of the measurer is minimal.

As it is unlikely that the flow direction inside the GT enclosure will be known, omnidirectional probes are the preferred flow transducer. If a directional device is to be used e.g. Vane or slotted thermal anemometer, the flow direction should be evaluated at each position before a measurement is made. Radiant heat from surfaces may affect the accuracy of thermal anemometers and this should be considered before any measurements are made.

Ideally, measurement of air speeds inside the enclosure should be made both (i) when the turbine is offline with the ventilation on, and (ii) with the turbine at base load. In practice, it may not be practical for personnel to be inside the enclosure when the turbine is running. Indeed, health and safety regulations may dictate that personnel are prohibited. If this is the case then remote sampling may be the only option if measurements are to be made when the turbine is at base load.

The measurement environment inside a GT is substantially different from that found in laboratories. As such, the measurement errors are likely to be greater. Errors associated with low air velocities (typically $<1\ ms^{-1}$) should be assessed using instrument manufacturers specifications, and quoted in the report. When recording measurements it is good practice to make sure the data is repeatable and reliable.

With the exception of the ultrasonic probe and the Pitot static tube, all instruments should be calibrated at regular intervals specified by the manufacturers. Whilst the Pitot static tube itself requires no calibration, the pressure gauge used with it should be calibrated. All calibrations should be ideally traceable to national standards.

For temperature measurement, the preferred instruments are K-Type (Chromel-Alumel) thermocouples, which are readily obtained and relatively inexpensive. Temperature measurements can be readily made with errors little, if any, greater than the manufacturers' maximum precision on the instruments themselves. Thermocouples can be purchased with known accuracies, and the purchase of new transducers may be more economic than the recalibration of existing transducers.

IR thermal photometry should also be considered where additional information could be used for operational purposes, or for other purposes such as a demonstrating that specified surface temperatures were not being exceeded at any point.

Surface temperatures are unlikely to be modelled in detail, but it is important to obtain between 5 and 10 measurements at different points for each discreet area that is being considered in order that reasonable average values can be produced.

Volume flow rates and temperature conditions at the air inlet(s) and exhaust point(s) will be required for any overall energy and mass balances.

Airflow and temperature should be measured at a range of locations throughout the enclosure. Ideally, airflow and temperature should both be measured at the same location. The number of locations measured will depend on the complexity of both the GT enclosure and of the modelling with which they will be compared. Smoke tests provide an excellent way to visualise the movement of the air inside an enclosure. Whilst the results are subjective, the tests can be used to identify areas of potential flow stagnation and therefore key areas where air speed measurements should be made.

It is recognised that there may be a limited amount of time in which in-situ measurements can be made. Therefore a compromise may need to be reached between accuracy and the number of measurements required. It is unlikely that fewer than 10 or so measurements will give sufficient information, but it is also unlikely that comparisons with 100 or so measurements would be practical. The measurement points should be chosen to reflect the subsequent use of the information and experienced personnel, in consultation with the CFD modellers, should make this judgement.

Once the GT ventilation system is operating satisfactorily static pressure measurements, carried out at regular intervals, are a useful method of monitoring the system performance. Possible measurement positions include; inlet to the fan, in the duct work close to the inlet(s) and outlet(s) to the GT enclosure and a reading of the pressure inside the enclosure.

A suitable and sufficient safety risk assessment will be required before any work takes place. This must take into account local safety procedures. PM84 contains further guidance.

5 REFERENCES

1. HSE Guidance note PM84: Control of safety risks at gas turbines used for power generation. 2003, 2nd Edition, HSE Books.

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