

# A MOST EFFICIENT DIAGNOSTICS TOOL FOR GAS TURBINE METERS: THE ACCULERT G – II

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## 1. INTRODUCTION

Turbine meters are very commonly used for custody transfer in the oil and gas industry. They have been type approved for fiscal metering for decades and in many countries, and they measure each day huge amounts of gas everywhere. While their biggest advantages are their good reliability and a low shift with time, together with a decent rangeability, their main drawbacks are their mechanical fragility and their sensitivity to poor installation conditions. Indeed, a too severe pressurisation might damage the thrust block of the rotor. A disturbed incoming flow profile will also induce an additional error from the turbine meter, which is designed for fully developed turbulent flow profiles.

Unlike new categories of meters, such as ultrasonic or Coriolis meters, turbine meters are not furnished with built-in electronics. So they don't offer any diagnostics features by themselves.

The AccuLERT G-II was designed to enhance turbine meters by providing a very efficient and easy means to monitor the metrological performances of turbine meters.

## 2. WHY DIAGNOSTICS TOOLS FOR TURBINE METERS ARE NEEDED BUT DIFFICULT TO FIND

### 5.1. Principles of a gas turbine meter

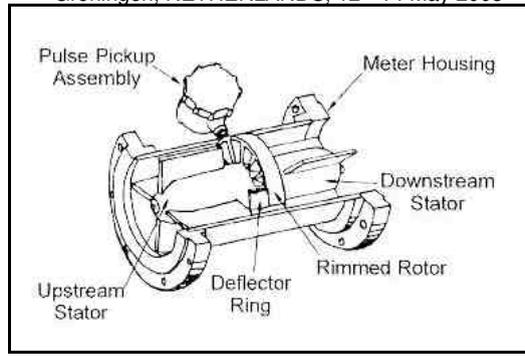
Turbine meters are inferential meters, which means that the flow rate which is indicated and totalized by the meter is based on the measurement of another quantity. In this case, turbine meters are basically velocity meters, and the velocity itself is known through the measurement of the angular velocity of the rotor. This can be summarised by the following equation:

$$Q_v = K \cdot \omega \quad (1)$$

where  $Q_v$  is the volumic flow rate (at meter's conditions),  $K$  is a factor depending on each meter and  $\omega$  is the angular velocity of the rotor. This linear equation is valid over quite a vast range, a typical rangeability of turbine meters being of 20 to 1.

As for the construction scheme, gas turbine meters are generally found as flanged spool pieces, with a solid housing including two stators on each side of a rimmed rotor (see **Picture 1**). The actual trend is to turn the upstream stator into a more and more effective flow straightener, so that the turbine will not be influenced too much by the flow profile generated by the geometrical elements located upstream of the meter.

In terms of outputs, all turbine meters are equipped with a mechanical counter, that is used for local reading. In addition, almost all mechanical counters include a low frequency (LF) emitter, that offers a volume pulse output to be exploited by the secondary instrumentation connected to the meter (such as flow computers or telemetry systems). Optionally, high frequency (HF) emitters can be installed on demand by manufacturers, either directly in line with the rotor, in which case they are usually called "HF #3", or in line with a secondary rotor integral with the former. In addition, a pressure probe near the rotor is part of the standard equipment of turbine meters.



**Picture 1 - Typical construction scheme of a gas turbine meter (from [2])**

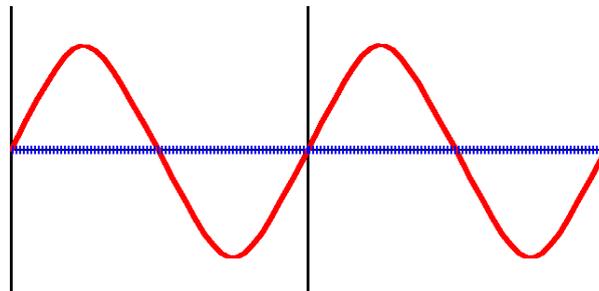
5.2. A basic technique of gas turbine meters' monitoring

A well known method of turbine meter monitoring is the spin test. The rotor is set into motion by an operator using a jet of compressed air, until the rotor reaches an acceptable angular velocity. The air jet is then stopped and the operator counts the time needed by the rotor to come to a complete halt. This length is then compared to a previously recorded value obtained when the meter was sound (this value can also be found in manufacturers' reference tables), providing a rough indication of the rotor's state. This method of course implies that the meter is dismantled. Though it demands only little equipment and can be used on site, this method gives a poor indication of the meter's behaviour. Its repeatability is also questionable, as the angular velocity reached with the compressed air might vary from one try to the other.

5.3. The choice of the HF rotor emitter as the only suitable output

A gas turbine meter offers relatively few output signals, and among these only the HF signal from the rotor emitter offers enough metrological information at a decent frequency.

The HF emitter is in fact made up of a reluctance-type pick-up coil threaded into the pick-up coil "boss" that has been welded directly in line with the rotor. The coil is usually connected to an explosion-proof (or intrinsically safe) junction box and some pre-amplifier, that powers the whole assembly, accordingly to the Namur specifications on proximity sensors (see [1]).



**Fig. 1 - Typical turbine HF output**

Fig. 1 shows the typical sinusoidal curve observed at the output of a pick-up coil: at each passing rotor blade, the magnetic flux in the coil bobbin is affected, inducing a change in resistance at the output terminals of the sensor.

The complete cycle of the turbine rotating generates a piece of a sine wave, one period for each blade. This signal is very rich, as it contains the information of each blade, and is updated at each rotation - its frequency can reach up to 4.5 kHz.

For example, one can easily imagine that a missing blade on the rotor will induce a missing part in the sine wave, that can be detected and interpreted by an adequate monitoring software.

### 3. THE DEVELOPMENT PHASE OF THE NEW ACCULERT G-II

In early 2000 Gaz de France contacted with FMC Measurement Solutions in order to test the AccuLERT ID 2000 device on gas turbine meters. At this time, the existing AccuLERT was specifically designed for liquid turbine meters, and was associated with a DOS software.

#### 5.1. Description of the existing AccuLERT ID 2000

The AccuLERT is basically a pre-amplifier and a HF signal analyser, to be directly connected to the rotor HF emitter (HF #3) (the input is then a sine wave) or via another preamplifier (the input is then a square wave).

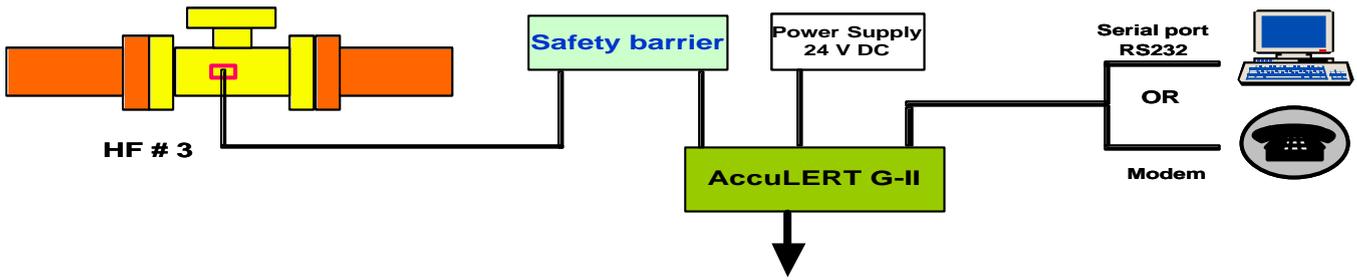
Its primary function is to perform real-time diagnostics of the turbine meter's performance by monitoring the consistency of rotation of the turbine. The AccuLERT is also capable of performing other tasks, such as bi-directional totalization, meter pulse recording, detection of flow direction, chronological alarms and periodic volumes recording.

It can be directly mounted on the meter's HF output (explosion proof version), or remotely connected to the HF output through wires, the AccuLERT itself being mounted on a DIN rail in the technical room, for example. In the natural gas industry, electrical safety regulations imply in this case the AccuLERT be connected via a Zener barrier (or equivalent)



Picture 2 - The AccuLERT II (DIN rail and explosion-proof versions) (picture by Gaz de France)

Picture 3 shows a typical installation of an AccuLERT for a natural gas application. Please note that the computer is needed only for configuration or on-site checks. The AccuLERT is designed to operate as a stand-alone device.



Picture 3 - Acculert's typical natural gas installation

5.2. Theory of operation

To perform the diagnostics function, the AccuLERT first digitises the HF signal from the emitter (see Fig. 2). An algorithm detects the y-axis crossings and stores the number of "positive time steps", representing the length during which the curve is above the y-axis. These time steps figures are stored in the AccuLERT's memory, and act as the basic data for a second algorithm.

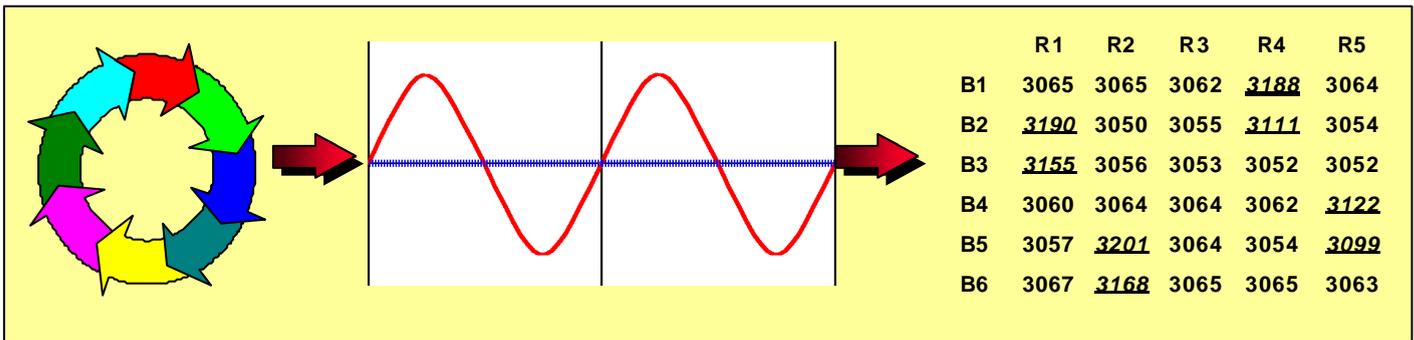


Fig. 2 - First phase of the Acculert Analysis

A second algorithm computes a set of 6 "signature fields", that is a sort of a meter's signature based upon the HF signal and which is frequently updated (between 1 and 5 seconds depending on the flow rate). Each signature field can be related to a specific mechanical feature of the meter, for example the blades' angle or the spacing between each of them, or the bearing resistance in relation to rotational momentum. The incoming flow profile is also characterised by the AccuLERT, through the computation of flow-related signature fields.

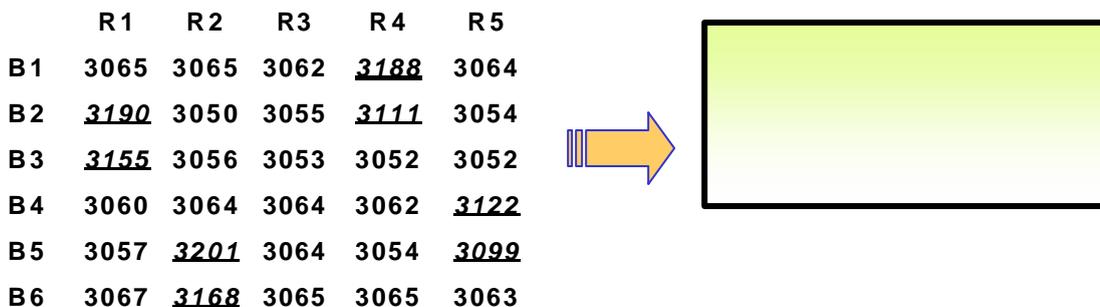


Fig. 3 - Second stage of Acculert's computation

Rotational stability is also analysed by the AccuLERT through integration of the flow rate : unstable integration values are indicative of non-uniform flow. For a better accuracy, the whole range of the turbine meter is divided into 7 zones, and the 6 Acculert signature fields are computed for a given flow rate zone. **By doing so, the Acculert characterises completely the behaviour of a given meter through 42 numerical values.** These 42 figures are stored in the AccuLERT's memory and can be saved in an archive file in a PC's hard drive. They represent what is called the reference signature of the meter, and will accompany the meter through its operational life.

**Table 1 - Denomination of the AccuLERT Signature fields**

AccuLERT signature field number	Name
Field #1	Blade average deviation
Field #2	Blade maximum deviation
Field #3	Integral deviation
Field #4	Ratio deviation
Field #5	Bearing average deviation
Field #6	Bearing maximum deviation

In real-time diagnostics mode, the AccuLERT provides the operator with the current (or "live") meter signature. This live signature is then compared to the reference signature stored in the AccuLERT's RAM memory, that was acquired on the same meter without any mechanical default and properly installed.

The comparison of both signatures is performed continuously and automatically by the AccuLERT itself, that generates alarms when certain conditions are reached. These alarms can be directed towards the operator in various ways: locally via the software, or remotely via modem or programmed switch contacts connected to secondary instrumentation.

The alarms are sufficiently explicit to bring the operator's attention on the right mechanical or installation cause ; see below the list of alarms and their probable causes:

**Table 2 - Alarms available in the AccuLERT G-II**

Alarm	Possible cause
Bent blade	Bent or missing blade
Non-Uniform flow	Bad flow profile (swirl and/or asymmetry) at the inlet of the meter
Bearing	Irregular rotation between each cycle
Missing pulses	Problem with the pick-up coil (HF emitter)
Meter down	meter stopped (no pulses)
Over spin	flow rate exceeding the maximal flow rate
Swirl	swirl in the incoming fluid flow
Accuracy	difference between LF and HF readings

### 5.3. First trial of the existing AccuLERT

The first trial of this device in the Gaz de France R&D facility in Alfortville was performed on one 100 mm nominal diameter turbine meter, having a maximal flow rate of 400 m<sup>3</sup>/h, and the fluid used was natural gas from the transmission network. This meter was submitted to various simulated defaults, such as bad

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bearing, clogging, bad bearing plus artificially increased drag on the rotor shaft. The AccuLERT had first been used on the mechanically sound and properly installed meter to record the reference signature in baseline conditions. Then for each sort of default the AccuLERT would give the real-time signature and propose a diagnostics for the meter.

The conclusions of this first set of tests was rather encouraging, as the AccuLERT proved indeed sensitive enough to detect the majority of the defaults with a good level of confidence. **Table 3** summarises the detection level of the device in each configuration:

**Table 3 - Results of the AccuLERT first trial**

Configuration	Average number of alarms	Comments
damaged bearing	1.92	the "bearing" alarm is generated 70 % of time
damaged bearing + rotor shaft friction	2.1	the "bearing" alarm is generated 50 % of time, together with the "non-uniform flow" one
clogging	1.7	except for low flow rates, the detection ate is satisfactory

The average in column 2 was calculated with the results obtained at five different flow rates evenly distributed over the rangeability of the meter.

The main conclusion of this first series of test is that the detection level reached was sufficient enough for an operator to judge a meter sound or not, and decide whether immediate maintenance is necessary or not. At this time, the AccuLERT was not always capable of precisely telling the exact cause of a meter bias and generated a mix of alarms rather than a single one. But even in these conditions it is obvious that an operator's attention would definitely be attracted by the AccuLERT's messages.

Other tests that were available to Gaz de France at that time also proved the efficiency of the AccuLERT to swiftly detect a strong pulsation in the fluid flow, which is another phenomenon likely to lead to severe misreadings by turbine meters. Pulsations can be caused by auxiliaries on the network in certain conditions, such as pressure regulators, compressors or heaters.

All these reasons account for the partnership that was fostered between FMC Measurement Solutions and Gaz de France concerning the development of a specific AccuLERT product for gas turbine meters.

#### 5.4. The Gaz de France facility in Alfortville

Fig. 4 shows one of the test benches of the Gaz de France facility in Alfortville that was used for the AccuLERT development study. The bench is fed with natural gas at 40 bar from the transmission network, 6 sonic nozzles mounted in parallel are operated as the reference meter of the bench, and 2 test lines can accept meters (one line can be operated while the other is being dismantled to prepare a different test). An accuracy of 0.2% is guaranteed concerning mass flow rate determination. This bench and its operators are certified by the COFRAC (French Comity for Accreditation) for metrological tests, all sensors are traceable to national standards.

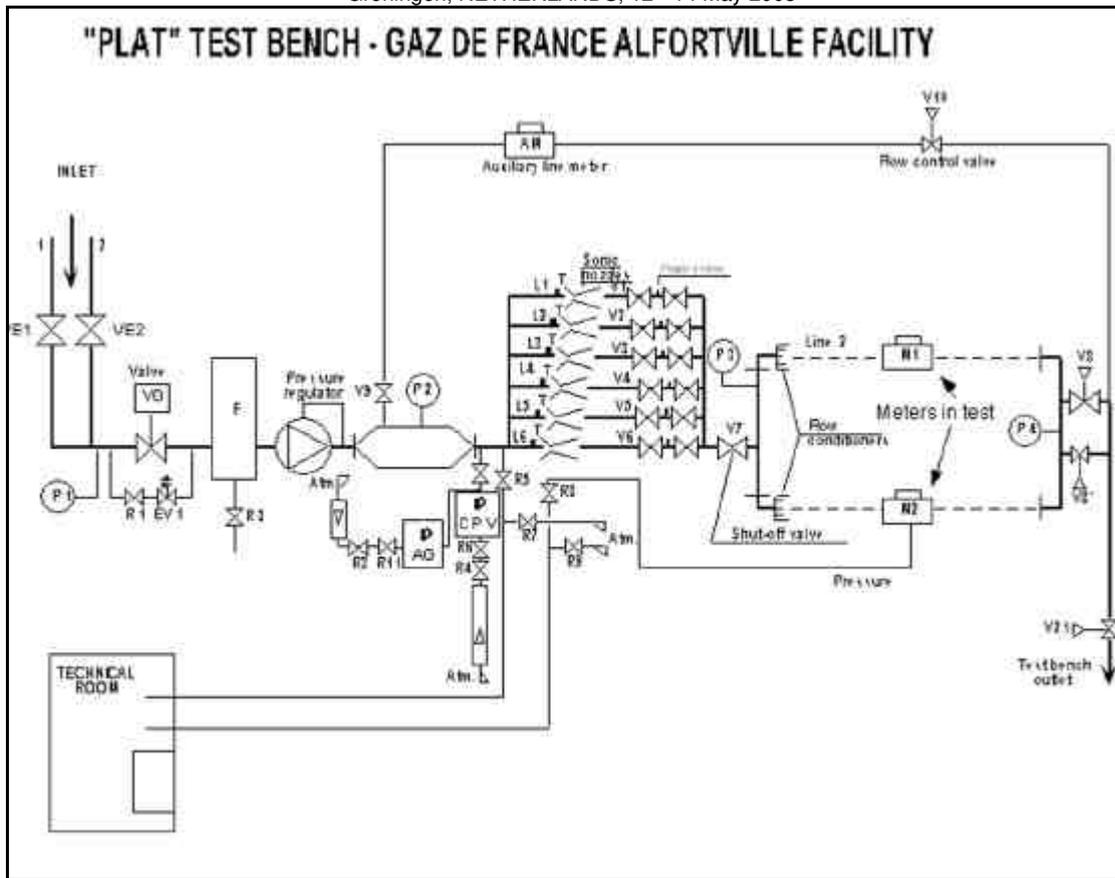


Fig. 4 - Scheme of the test bench used for the study

5.5. The test program engaged by Gaz de France and FMC

The base of the co-operation between Gaz de France and FMC was the collecting by Gaz de France of as much information as possible on gas turbine meters in order to customise the existing algorithms for this family of meters. A comprehensive study involving gas turbine meters from five different manufacturers from the European market (hereafter named A to E) was started. All meters would undergo a series of tests in different configurations, during which both an AccuLERT signature and a metrological error curve would be done in the Gaz de France Alfortville facility.

All the data acquired during this extensive campaign would then be furnished to FMC software specialists for enhancement of the diagnostics features of the AccuLERT G-II.

The detail of the test program can be found in **Table 4**. Each crossed cell of this matrix represents both an AccuLERT signature acquired and a metrological error curve performed on a critical-nozzle equipped test bench. The AccuLERT signature fields and the meter error were computed for 7 flow rates distributed over the whole range of the meter.

The AccuLERT G-II used for this series of tests was a prototype using updated firmware.

**Table 4 - Test program performed by GDF**

Meter	Baseline conditions	Damaged bearing	Clogging	Double bend 2D	Double bend 5D
Meter A 80 mm	X	X	X	X	X
Meter B 80 mm	X	X	X	X	X
Meter C 80 mm	X	X	X	X	X
Meter D 80 mm	X	X	X	X	X
Meter E 100 mm	X			X	X
Meter A 150 mm	X			X	X
Meter B 150 mm	X			X	X
Meter C 150 mm	X			X	X
Meter D 150 mm	X			X	X

- The baseline conditions were reached with the meter installed downstream of more than 100 D of straight pipe length, with no mechanical defaults.
- The damaged bearing default was artificially reproduced by stuffing abrading paste between the balls inside the rotor bearings.
- The clogging was obtained on a special test bench in Gaz de France facility, where a controlled amount of iron dust can be injected into the fluid flow at the meter's location.
- The double bend tests, with the meter located 2D or 5D downstream of the nearest bend, featured a typical High Level ISO Perturbation Unit, with a half moon plate inserted between two elbows out-of-plane ; this configuration is well known as a strong swirl and asymmetry generator.

These tests enabled Gaz de France to build a database of Acculert signatures related to typical field mechanical defaults and bad installation configurations.

#### 4. RESULTS

All the results found below are related to the AccuLERT G-II intermediate prototype used during the campaign.

##### 5.1. Influence of the flow rate

Fig. 5 shows the variations of the 6 signature fields computed by the AccuLERT over the 7 flow rate zones defined by the user, for meter C in baseline conditions. One can see that signature field #3 (Integral deviation) is quite stable over the seven zones, but on the other hand, fields # 4 and 6 (resp. Ratio deviation and Bearing maximum deviation) tend to increase with the flow rate.

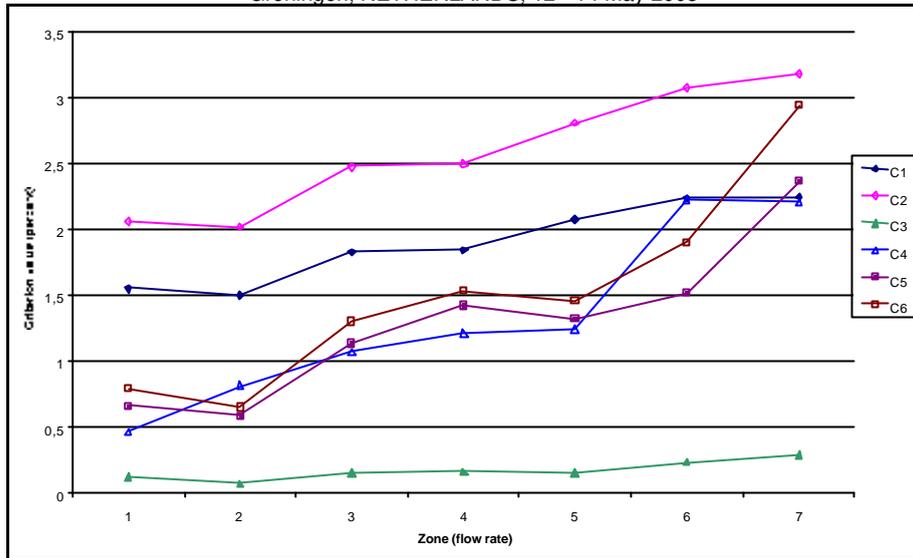


Fig. 5 - Signature fields values over the 7 flow rate zones for meter C (baseline conditions)

Although the meter is properly installed and mechanically in good shape, **the signature strongly depends on the flow rate and on the rotation speed of the turbine**. These variations in the computed signature fields account for the total range of a meter being divided into seven zones, as this is the best method to maintain a good accuracy and sensitivity of the AccuLERT, whatever the flow rate.

5.2. Influence of the manufacturer (meter type)

Fig. 6 shows the values of the AccuLERT signature fields gathered for the five meters in DN 80 that were studied (meters A to E). Depending on the signature field, the dispersion of the values is more or less obvious. For example the integral deviation value seems pretty stable, almost constant for the five meters, but on the contrary, blade or ratio deviation values are very dependent on the type of meter (the difference can reach 200 % from one meter to the other). These data illustrate why a complete signature is required for each meter individually.

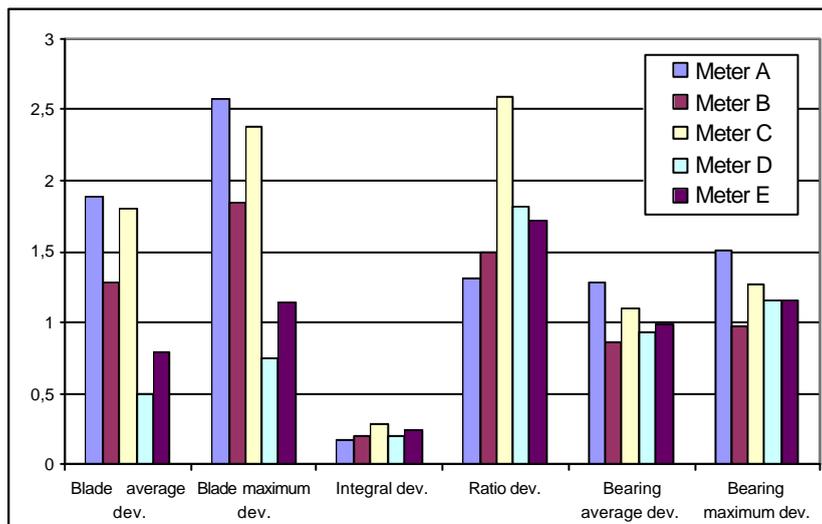


Fig. 6 - AccuLERT signatures in baseline conditions for meters A to E

5.3. Default detection ability of the AccuLERT G-II

The alarm generation of the AccuLERT is based upon the comparison of the signature fields reference and live values. If the live value exceeds the reference value, the algorithm triggers one or several alarms.

Fig. 7 shows for meter B in flow rate zone #2 the reference values (thick line) and live values (histograms) in different configurations.

When one (or more) histogram is above the thick line that means that a signature field has increased so much that one (or more) alarm(s) is to be triggered by the built-in algorithm.

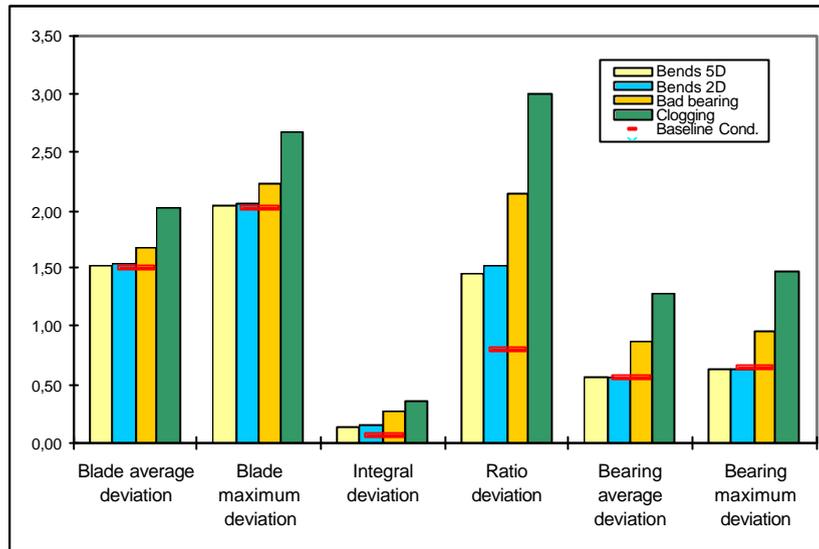


Fig. 7 - reference and live signature fields' values for meter B

In the example that is shown, all signature fields are above the reference in clogging configuration (histogram on the far right): as a consequence all possible alarms are triggered. But in the 2D double bend configuration (histogram of the far left), the blade average and maximum deviations are just below the reference, so no blade-related alarm is triggered. All other alarms are present, as the other fields' values exceed the threshold.

By defining the detection ratio of the AccuLERT as the number of occurrences when at least one alarm is triggered over the total occurrences, here are the results gathered during the campaign for three basic defaults:

**Table 5 - Detection ratio of the AccuLERT G-II**

Default	Detection ratio
Bad bearing	> 75 %
Clogging	> 75 %
Bad flow profile (swirl and/or asymmetry)	> 33 %

The detection ratio is very high for purely mechanical defaults, as they are pretty easy to reproduce and as the AccuLERT's algorithm is very efficient in analysing the rotation scheme which is directly affected by such defaults.

5. DESCRIPTION OF THE ACCULERT G-II MAIN FEATURES

5.1. New features

The improvements of the new AccuLERT G-II version compared to the previous one are of different nature. The hardware has been upgraded to allow an easy and instant connection to all types of meters using NAMUR signal. The built-in algorithm has been improved and tuned according to the results of the tests performed by Gaz de France. The detection ability of the AccuLERT has never been so efficient as in the G-II.

The end user will also appreciate the features of the new Windows®-based software: the Modbus Explorer.

Using a Windows® Explorer-based approach, the Modbus Explorer allows the operator to navigate through configuration or diagnostic report screens, access live data or previously saved records, and even visualise graphs through a user-friendly and intuitive interface.

**Fig. 8** shows a daily diagnostic report screenshot, where the information related to one day is displayed. One can notice the current and maximum signature fields' values gathered in a table, close to the alarms list. By comparing the data and alarms over a period of several days, the end user can easily check whether the meter is sound or not, and whether the alarms are always the same. This view can be exploited to determine the starting point of a default, i.e., the day when an alarm was first triggered.

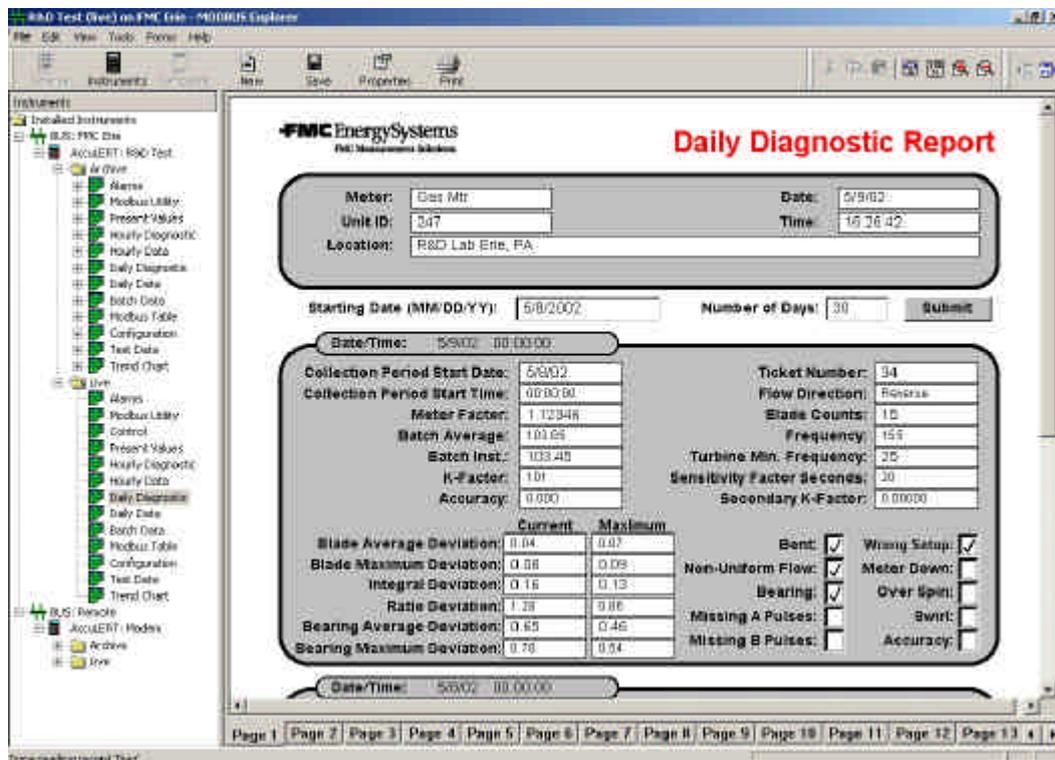


Fig. 8 - Modbus Explorer Daily Diagnostic Report screenshot

**Fig. 9** shows a trend chart, drawing the signature fields' values over time. This screen is designed for live monitoring, when the user connects the AccuLERT for the first time, or when a special behaviour is

encountered or expected. This view is very useful to assess the stability of flow rate or turbine parameters.

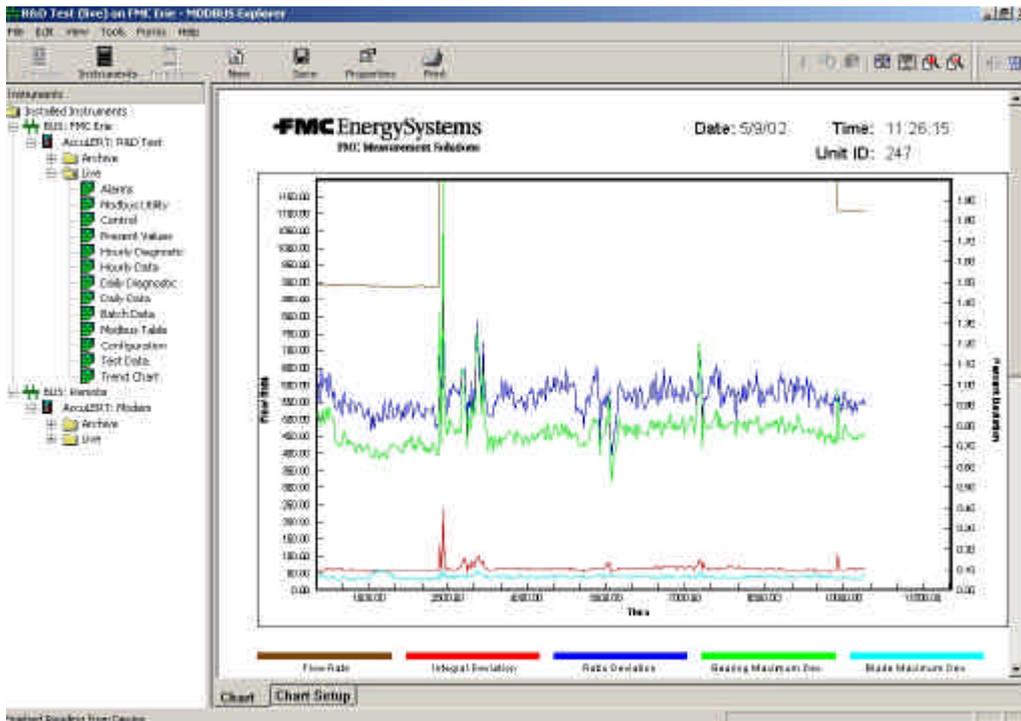


Fig. 9 - Modbus Explorer Trend chart screenshot

## 5.2. Benefits to be expected from its installation

The AccuLERT's diagnostic abilities, previously emphasised, account for the AccuLERT being a very efficient and useful tool for a metering expert or network manager.

Everyone should be aware that even a slight error of 0.1%, over a long period of time and on large amounts of gas, can end up in a huge profit loss for any transmission or distribution company. The AccuLERT brings a cost-effective, relatively cheap answer (the target price is roughly 1500 €) to all needs of gas turbine meter monitoring. Its software clearly indicates the most probable cause of error, and the detection algorithm proved very efficient for both mechanical and installation effects.

## 6. CONCLUSION

The co-operation between Gaz de France and FMC Measurement Solutions led to the development of the AccuLERT G-II. This product answers the need of an easy, efficient tool for on-line monitoring of gas turbine meters.

Its ability to detect and analyse both mechanical and flow-related metering errors has been improved and checked through the extensive study that was performed: the detection ratio of a bad bearing-type default exceeds 75 %.

The development phase should come to an end before 2003. The AccuLERT G-II will then be made commercially available by FMC Measurement Solutions, providing the only efficient tool for gas turbine meters monitoring.

7. REFERENCES

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