Index

Paper 7.2

Development of a Diagnostics Tool for Gas Turbine Meters: the "Acculert G – II"

Mr Bertrand Reeb, Gaz de France
Mr Oliver Joachim, FMC Measurement Solutions

Development of a Diagnostics Tool for Gas Turbine Meters: the "Acculert G – II"

Mr Bertrand Reeb, Gaz de France
Mr Oliver Joachim, FMC Measurement Solutions

1. INTRODUCTION

Turbine meters are well known for their good metering abilities and repeatability, which accounts for their being the most widespread technology for custody transfer all over the world. In France only, 80% of all meters installed on the transmission network are turbines. These good performances are due to their principle of operation and to the choice of good quality mechanical elements, such as a well balanced rotor and bearings. Yet this can turn into a disadvantage, as turbine meters are fragile and can be damaged by solid particles in motion in the fluid, or even by a too severe pressurisation.

With the current practice, the defaults inducing metrological errors (misreadings) can be detected only during periodic verifications, when the meter is dismounted and installed on a test bench. In France these verifications are planned every five years. Regularly a certain number of turbine meters is proved to be more or less severely misreading after this five year period. Both customers and gas companies are concerned by misreadings, and the need to improve the confidence in the meters' accuracy and reliability is obvious.

When it comes to monitoring solutions suited for turbine meters, some exist, like the spin test, but they are not very sensitive and none can avoid a costly and time-consuming dismounting of the meter. That is why the need for a practical and efficient tool for on-line monitoring of turbine meters was the starting point of an internal research program at Gaz de France.

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

2.1 Principles of a gas turbine meter

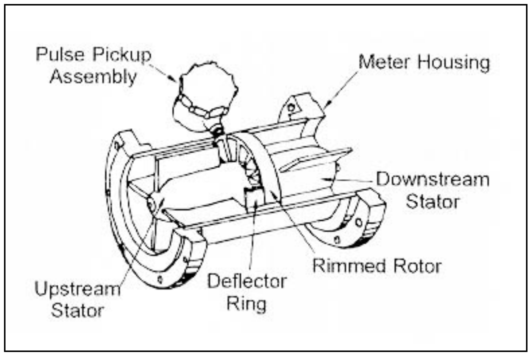
Turbine meters are inferential meters, which means that the flow rate which is indicated and totalized by the meter is based on the measurement of another quantity. In this case, turbine meters are basically velocity meters, and the velocity itself is known through the measurement of the angular velocity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

$$Q_V = K \cdot \omega \qquad (1)$$

where Q_v is the volumic flow rate (at meter's conditions), K is a factor depending on each meter and ω 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 can be locally visually exploited by an on-site operator. In addition, 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])

2.2 Principles applicable for gas turbine meters monitoring

A first 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 reference tables), providing a rough indication of the rotor's state. This method of course implies that the meter is dismounted. 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.

Another approach is to consider turbine meters as a category of larger turbo-machines. For these machines, a very efficient method of monitoring makes use of the vibratory signal as an indicator for the rotor and bearings' status. Vibratory-based methods can detect defaults such as excessive friction or rotor imbalance, with the greatest advantage of providing a diagnostic while keeping the machine in operation.

A comprehensive study of vibratory-based methods applied to gas turbine meters was performed by Gaz de France with the hope that such methods would work for this type of devices, but a major difficulty was encountered. The signal over noise ratio proved indeed very poor with turbine meters, especially when a regulator is operating near the turbine, which is the case in most French metering stations. The light weight of the rotor and the good quality of its bearings proved a definitive drawback with respect to the use of a vibratory-based monitoring technique. On the contrary, the same method applied to positive displacement rotary meters proved very efficient and fully operational.

As part of the same research project, a method based on the correlation between the differential pressure across the meter and the flow rate was tested. Here again the good quality of the meters' construction played against the possibilities of diagnostics, as the pressure to be measured did not exceed a few millibars, which is a very low value especially for a field differential pressure transducer, and as the upstream pressure probe location depended heavily on the station's design and was not repeatable from one station to the other.

2.3 The HF rotor emitter as the only suitable output

All these reasons account for the rotor HF output to be the natural diagnostics-aimed signal.

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 signal specifications (see [1]).

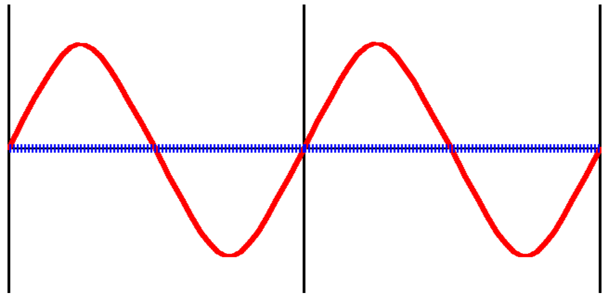


Fig. 1 - Typical turbine HF output

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.

3.1 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 connected to the HF output through wires, the AccuLERT being mounted on a DIN rail in the technical room, for example.

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

When performing the diagnostics function, the AccuLERT computes a set of 6 "signature fields", that is a sort of a meter's signature based upon the HF signal. Each signature field can be related to a specific mechanical feature of the meter, for example the blades' angle and spacing between each other, 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: indeed, a certain shift in the rotation's repeatability can be seen as evidence of incoming swirl or asymmetry. 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**.

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 meter signature. This current signature is then compared to a 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 by a built-in algorithm, 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

3.2 First trial of the existing AccuLERT

The first trial of this device in our Gaz de France facility in Alfortville was performed on one turbine meter, in DN 100, having a maximal flow rate of 400 m^3/h, and the fluid used was natural gas from the transmission network. This meter was subject to various simulated defaults, such as bad bearing, clogging, bad bearing plus artificially increased drag on the rotor shaft. The AccuLERT was first 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 rate is satisfactory

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

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.

3.3 The Gaz de France facility in Alfortville

Fig. 2 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 dismounted 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.

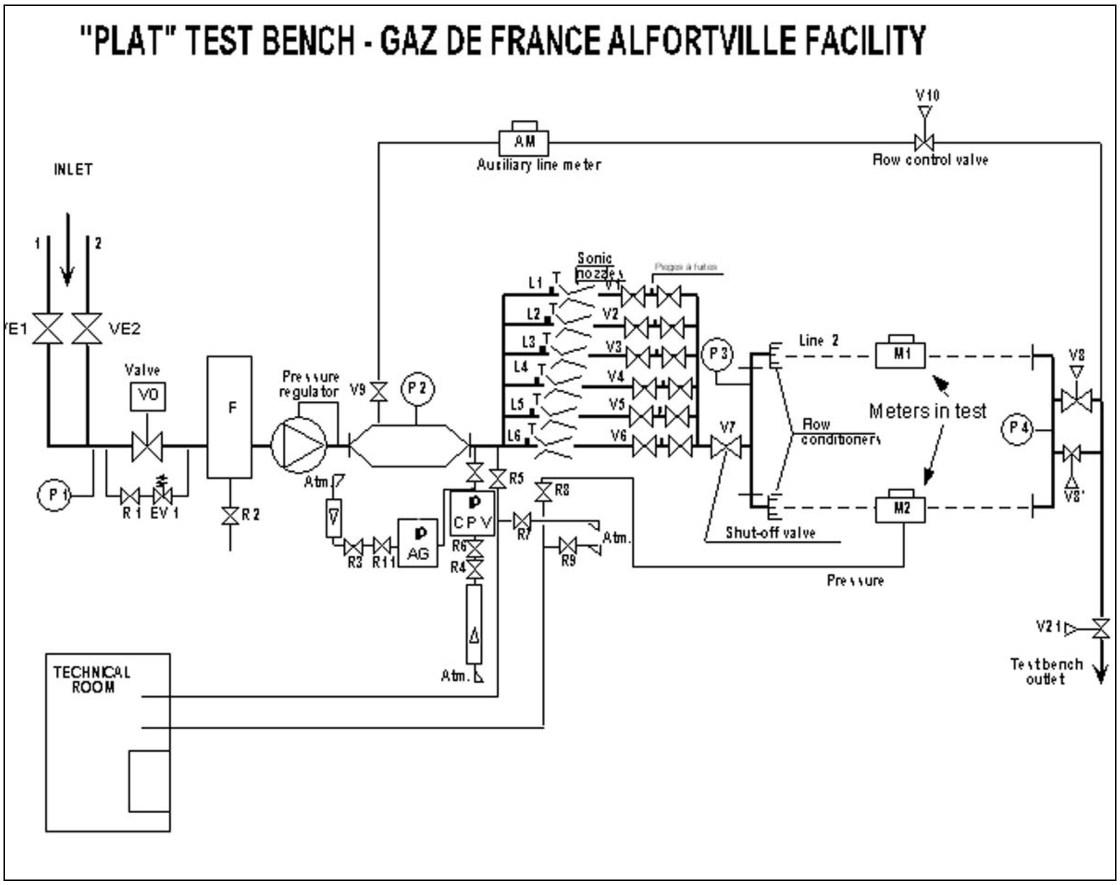


Fig. 2 - Scheme of the test bench used for the study

3.4 The test program engaged by Gaz de France and FMC in 2001

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.

4.1 Influence of the flow rate

Fig. 3 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.

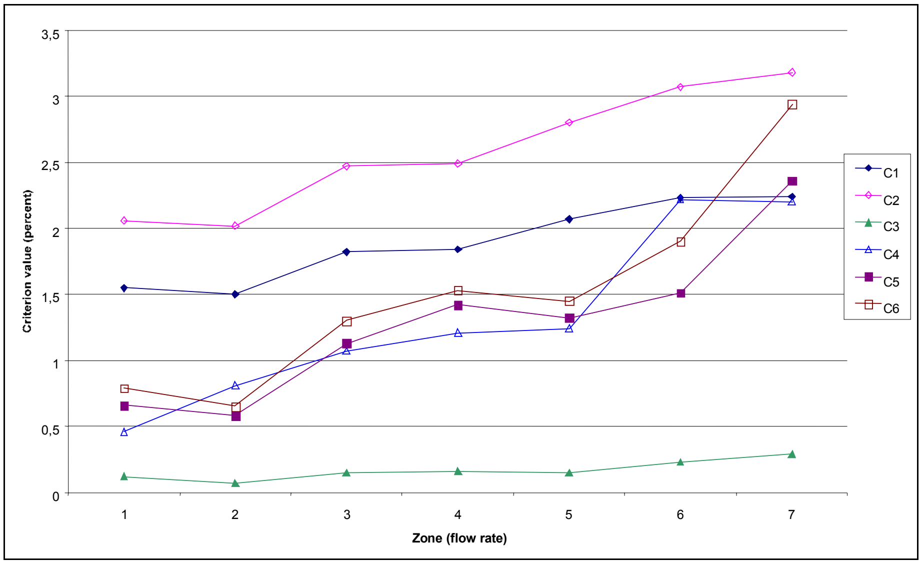


Fig. 3 - Signature fields values over the 7 flow rate zones for meter C (baseline conditions)

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.

4.2 Influence of the manufacturer (meter type)

Fig. 4 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.

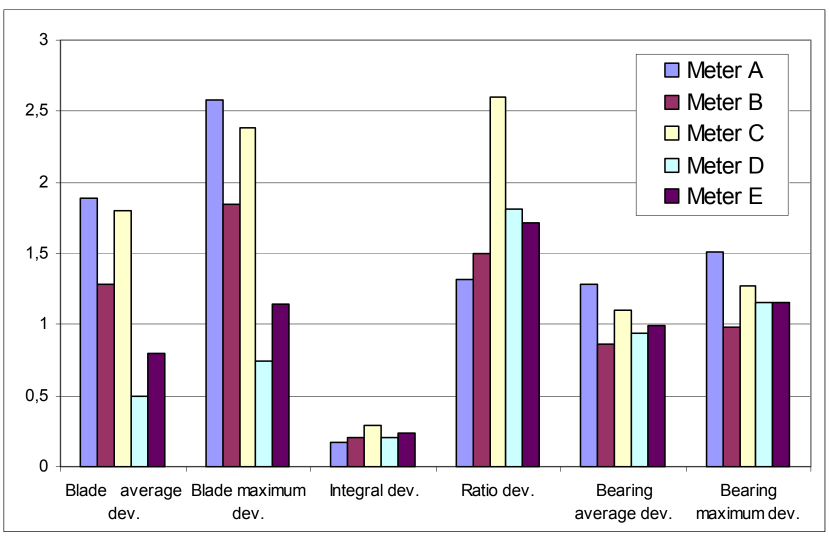


Fig. 4 - AccuLERT signatures in baseline conditions for meters A to E

4.3 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. 5 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.

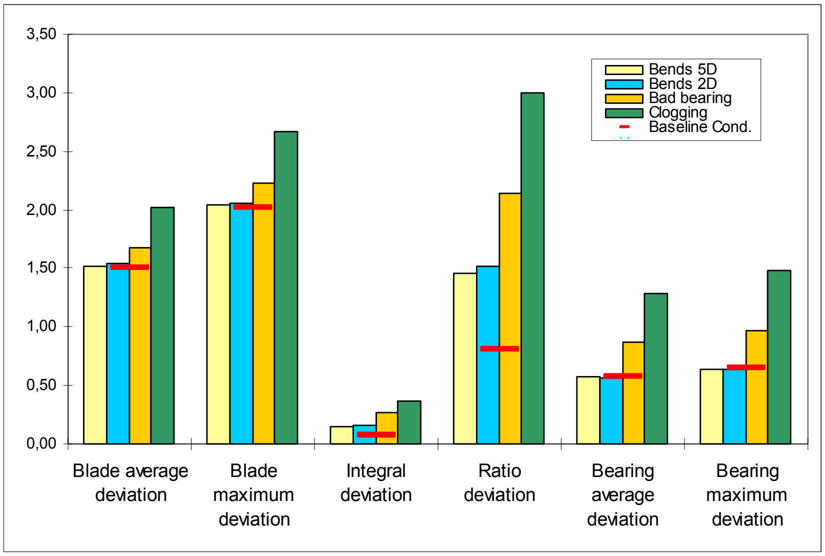


Fig. 5 - reference and live signature fields' values for meter B

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. 6 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.

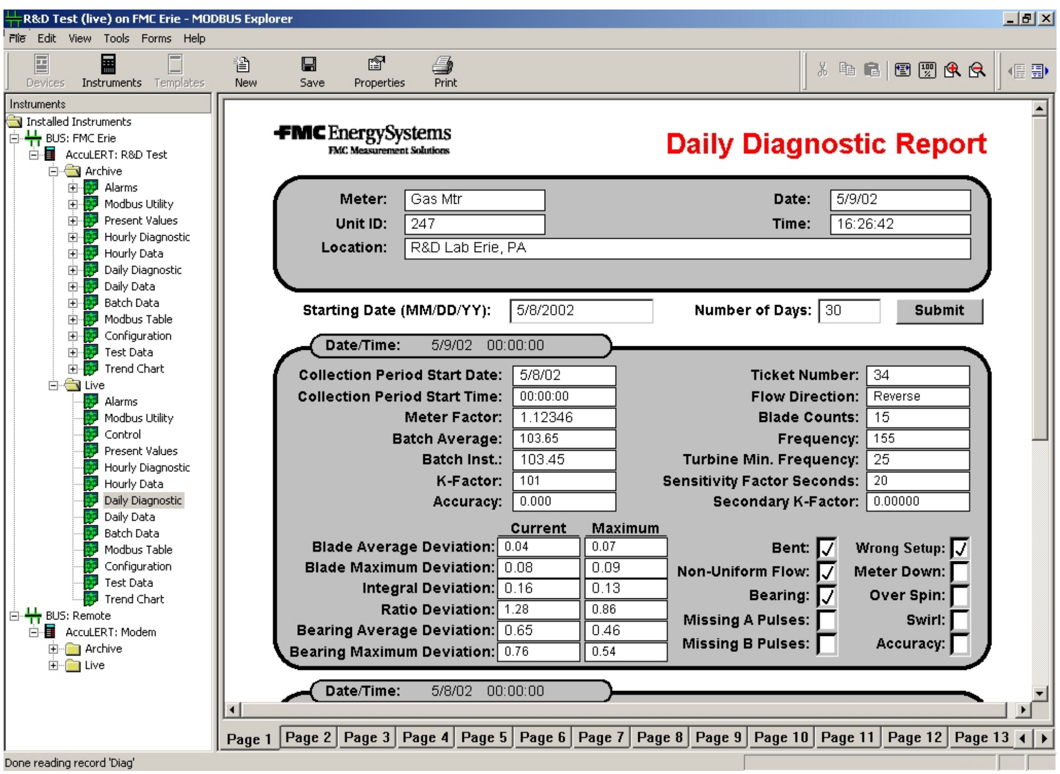


Fig. 6 - Modbus Explorer Daily Diagnostic Report screenshot

Fig. 7 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.

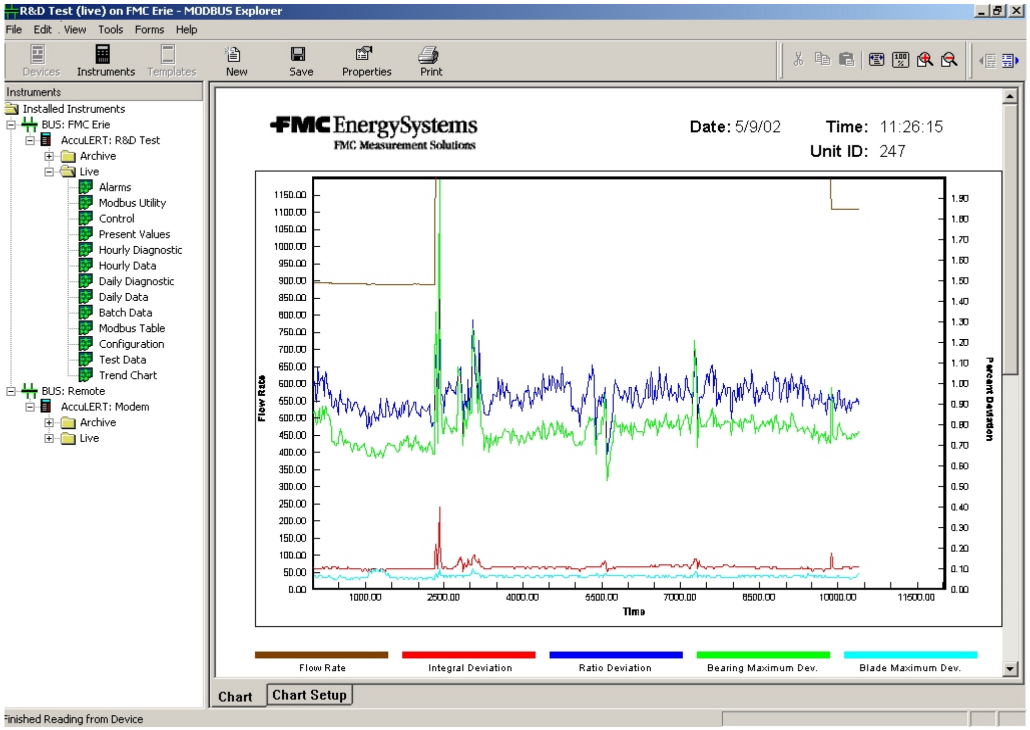


Fig. 7 - Modbus Explorer Trend chart screenshot

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

[1] NF C63-003 (IEC 60947-5-6:1999), Low-voltage switchgear and control gear – Part 5-6 control circuit devices and switching elements – DC interface for proximity sensors and switching amplifiers (NAMUR)

[2] FMC Measurement Solutions, Installation / Operation of the AccuLERT ID-2000 manual, Bulletin MN02008

[3] FMC Measurement Solutions, Fundamentals of liquid turbine meters technical paper 103B, Bulletin TP02001

[4] FMC Measurement Solutions, Smith AccuLERT Smart Pre-amp ID 2000 Specifications, Bulletin SS02015P

8. CONTACTS

Bertrand REEB, Direction de la Recherche Gaz de France, 1 Chemin de Villeneuve, 94140 Alfortville FRANCE, tel: +33 1 45 18 85 35, email: bertrand.reeb@gazdefrance.com

Alf Erling Smorgrav, FMC Kongsberg Metering AS, Kirkegårdsveien 45, P.O. Box 1012, N-3601 Kongsberg NORWAY, tel: (+47) 32 28 80 74, email: alf.erling.smorgrav@fkm.fmcti.com