A procedure to evaluate the electromagnetic immunity degree of a data acquisition system

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Abstract-The paper deals with the empirical evaluation of the electromagnetic immunity degree of PC-based data acquisition systems. A first series of experiments is carried out subjecting the systems to known and standardized disturbances in order to check if and how their performances are corrupted. A second series of experiments is performed in locations where unknown electromagnetic disturbances are present with the aim to find a method for the evaluation of the actual effect of the disturbances. By means of the proposed approach, when a data acquisition system is used to perform a measurement, it is possible to decide if the actual measurement conditions are adequate for the measurement targets. In some cases, moreover, the procedure allows the implementation of algorithms to compensate for the disturbance effects.

I. Introduction

Data acquisition systems (DASs) are often approached as a standard personal computer with a connected data acquisition board (DAQ). In fact, this solution is appealing manly on account of its flexibility, easiness of use and low costs. However, given that often the applications of the PC-based DASs concern with monitoring of production lines and super visioning of industrial processes, these systems can operate in a hostile electromagnetic (EM) environment due to various devices located nearby, that generate conducted and radiated interferences during their normal operation. In these cases, the DASs are interested by EM disturbances that could compromise their nominal performances.
Therefore, with the aim to assess the EM immunity degree of the DASs to the EM disturbances and to quantify their effects, we decided to subject different typology of DASs to various EM perturbations.
Since there are no particular standards concerning the DASs, in order to apply standard requirements and criteria for the immunity tests, we take into account the IEC-61236 standard [1], which specifies minimum requirements for immunity and emissions regarding electromagnetic compatibility (EMC) for electrical equipment for measurement, control and laboratory use. In this standard, the interfaces of the equipments with the external EM environment are classified in five ports: enclosure port; AC power port; DC power port; earth port; input/out port. The considered EM phenomena are: radiated radio-frequency (RF) disturbances; bursts; surges; conducted RF disturbances; voltage interruptions; electrostatic discharges; rated power frequency magnetic field. For each phenomenon and for the suitable port, the immunity requirements and limits are given for normal environments, industrial locations and for controlled EM environments. Each of the considered disturbances is described in detail in the corresponding standard of the IEC-61000-4 series [2].
The prescribed performance criteria for the evaluation of the immunity test results are the following:

- Criterion A: during testing, normal performance within the specification limits.
- Criterion B: during testing, temporary degradation, or loss of function or performance which is self-recovering.
- Criterion C: during testing, temporary degradation, or loss of function or performance which requires operator intervention or system reset occurs.
- Criterion D: degradation or loss of function which is not recoverable due to damage to equipment, components, software, or loss of data.

Although there are no particular rules for PC-based DASs, these instruments show some peculiarities: unlike the stand-alone instruments, which can be characterized by the same manufacturer as for the EMC specifications, they are constituted of various components (cables, connectors, DAQs, PCs), often provided by different manufacturers. Even having access to the EMC specifications of each component, the extension of these specifications to the whole measurement chain is not completely straightforward. All the chain has to be considered as unique equipment under test (EUT), and for each particular configuration, the immunity tests must be carried out. Only in this way, a complete characterization of the DAS from the EMC viewpoint can be carried out. Moreover, the manufacturers often declare the EM immunity specifications only with relation to the criterion B, therefore the user can only know that the component, under the EM disturbances prescribed in [1], is designed to keep on working, without receiving any information about the performance degradation. Since for a correct employment of a DAS there is the need to know if its metrological characteristics stay within the specification limits, we decided to perform the immunity tests not only checking if the criterion B is satisfied, but also monitoring some parameters which can be useful to evaluate the overall performances of a DAS. In particular, by means of time and frequency analysis, the offset, gain and Signal to Noise and Distortion Ratio (SINAD) values were registered. As for the experiments setup and management, we adhere to the procedures described in the IEC-61000-4 series.

II. The immunity tests

The core of a DAS is the data acquisition board. We have considered four different National Instrument™ DAQs (whose technical characteristics are reported in Table I), varying the configuration of the external connector boxes and of the signal cables and considering both full-shielded and not-shielded configurations.

TABLE I. Characteristics of the tested DAQs

DAQ Model	AT-MIO 16E-10	PCI-MIO 16XE-10	DAQCard-AI 16XE10-50	PCI 6110
BUS Type	ISA	PCI	PCMCI	PCI
Number of channels	16	16	16	4
ADC Type	Successive approximation	Successive approximation	Successive approximation	Delta sigma
Resolution (bit)	12	16	16	12
Maximum sampling rate (kS/s)	100	100	200	5000
Maximum input signal ranges (V)	± 10	± 10	± 10	± 42
Bandwidth (kHz)	150	255	39	7200

The PCMCI DAQ is inserted in the notebook AUSUS™ 7300; the other three DAQs are inserted in the appropriate slot of various PC motherboards mounted on different PC cases.
The DAQs are linked to a shielded connector box NI SCB68 through a shielded cable NI SCH6868 (1m). We tested also a not-shielded configuration linking the DAQs to a CB-68LP connector block trough a R6868 ribbon cable (1m). To link the measurement point to the various connector boxes, we use a RG-58 type coaxial cable (0.5 m) or a LMR0-600-DB double-shielded coaxial cable for the full-shielded configurations.
The environment and the instrumentation used to generate the EM disturbances are full-compliant with [2].
As inputs for the tested DASs, DC and sinusoidal signals are generated by the Agilent™ 33120A function and arbitrary waveform generator.
All the measurements are performed in differential mode, sampling at the maximum rate and setting the gain to 1. Static offset and gain values are calculated by drawing up the transfer characteristic, which, in its turn, is obtained from a five-point least minimum squares method. The SINAD values are calculated using a not-coherent sampling and consequently a Hanning windowing is used.
After the warm up of the generator and of the EUT, we verified that the measured offset, gain and SINAD values are compatible with the manufacturer specifications; and after the evaluation of the offset and SINAD measurement stability and repeatability, we submitted the EUTs to the EM disturbances prescribed in [1].
In order to test the DASs under radiated emissions, we performed various tests inside both an anechoic chamber and a GTEM cell, varying PCs, DAQs, cables and connector boxes of the tested DASs, the reciprocal positions and orientations of these components and the frequency and strength of the disturbance fields. In all cases, we observed that spurious frequencies arise during the signals acquisition [3]. These spurious components are a DC component, the disturbance modulating signal and its harmonics; in the prescribed frequency range, the disturbance carrier signal and its harmonics are completely filtered by the limited bandwidth of the tested instruments. In any case, mainly for the not-shielded configurations, the presence of these spurious frequencies reduces the SINAD value and alters the offset value. By analyzing the acquired signals, we verified that the amplitude of the spurious frequency components (and consequently the coupling intensity and the immunity level) is:

- weakly depending on the DAQ, motherboard and case models and strongly depending on the shielding dress of cables and connector boxes;

- slightly depending on the PC and connector box position and strictly depending on the signal cables position;
- strictly depending on the disturbance strength, but not-depending on the disturbance frequency, except when the system resonates, allowing a much tighter coupling and strongly increasing the spurious frequencies amplitude.

As for the conducted disturbances, we started the experiments with the bursts using a not-shielded configuration. During the burst injection into the supply cable, visible spikes, superimposed to the sinusoidal signal, appear causing a temporary variation of the offset and SINAD values. However we noticed that the acquired disturbance level depends on the reciprocal position of the signal cables and the supply cable, where the bursts are injected. This means that the disturbance injected in the supply cable is radiated by the cable itself and produces an EM interference with the EUT. With the aim to quantify the radiated coupling mechanism, we tested a full-shielded configuration. With this arrangement, no effects are observed when the EUT is subjected to the bursts; therefore, from this experiment, we can deduce that the coupling mechanism between disturbance and EUT is only radiated and only caused by the emissions of the supply cable [4]. To find another evidence of this thesis, we tested again the not-shielded configuration of the EUT, but shielding the supply cable. Also in this way, the DAS is immune to the bursts.

We tested the DAQs changing PC cases and motherboards and in each case we observed the same behaviour, namely that there are no conductive coupling paths, but only radiated coupling paths between the EM disturbance and all the tested EUTs. As a consequence the coupling intensity and the disturbances effects are strictly depending on the experimental layout, in particular on the length, the dress and the reciprocal position of the signal cables and of the supply cable. This entails that the reproducibility of the results cannot be ensured if at least length, shielding and mutual position of the cables are not defined and characterized [4]. But actually in the IEC 61000-4-4 standard there are no particular rules regarding these aspects, since the standard implicitly considers just conductive coupling paths.

Injecting into the supply cable surges and repeating the same methodology employed for the bursts, we obtained similar results, specifically that the full-shielded configurations are practically immune to the surges, while with a not-shielded configuration the surges effects are manifestly visible on the acquired signals. Also in this case the coupling mechanism is only radiated and, consequently the surges impact is strictly depending on the length, the dress and the reciprocal position of the signal cables and of the supply cable.

Subjecting the EUTs to the conducted RF fields, it can be noticed that once more the coupling mechanism between disturbance and EUT is only radiated. Therefore, for the full-shielded configuration of the EUTs, no visible effects appear while a RF threat crosses the supply cable, and no variations of offset, gain and SINAD values were observed. Repeating the experiments onto the not-shielded configuration, the emission radiated by the supply cable couple with the EUT and spurious frequencies arise during the signals acquisition. These spurious components are a DC component, the disturbance carrier signal and its harmonics and the disturbance modulating signal and its harmonics. Of course some of these components can appear in their alias version or can be completely filtered, depending on the sampling frequency and on the instrument bandwidth. In any case the presence of these spurious frequencies reduces the SINAD value and alters the offset value.

When the tested EUTs are subjected to 1-cycle supply interruptions, no visible effect appears during the signals acquisition, either with full-shielded configuration or with not-shielded configuration.

Contact and air discharges in both polarities were applied in various points of the EUT, starting from 1 kV and increasing the test level value with a step size of 0.5 kV. No visible effects were observed and therefore, with respect to the not-perturbed conditions, no changes were detected in the offset, gain and SINAD values.

Eventually, the EUTs were subjected to 50 – 60 Hz magnetic field reaching the 30 A/m strength level prescribed for industrial locations. Also in this case, no effects were observed.

III. The proposed approach

By analyzing the results of the tests, we are able to assess the immunity degree of a generic DAS when it is subjected to the standardized disturbances prescribed in [1], deducing that only under the disturbance levels prescribed for industrial location and mainly for not-shielded configurations, the instrument performances reveal perceptible degradations. However, from the obtained data, we can not establish if, considering the real shielding and grounding conditions of the measurement chain, the actual EM environment, where the instrument will actually operate, are able to compromise its metrological characteristics. Therefore, it is necessary to define a procedure which, by means of a desirably simple and fast test, allows the assessment of the actual immunity degree to the EM disturbances that are actually present in the place where the measurement is performed.

To outline this procedure, we started analyzing two interesting phenomena: we experimentally noticed that the disturbance effect is linearly added to the measurement signal (obviously excluding the cases which cause the A/D converter saturation). For instance, in fig.1 and in fig.2 we report a 0.5 kV burst effect on an acquired 0 V DC signal and on an acquired 9 V 10 Hz sinusoidal signal. The used DAQ is the AI 16XE10-50 model with a not-shielded configuration, sampling at 200 kS/s rate.

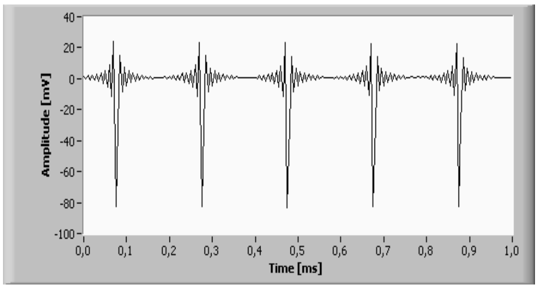

Fig.1 - 0.5 kV burst effect on a 0 V DC signal

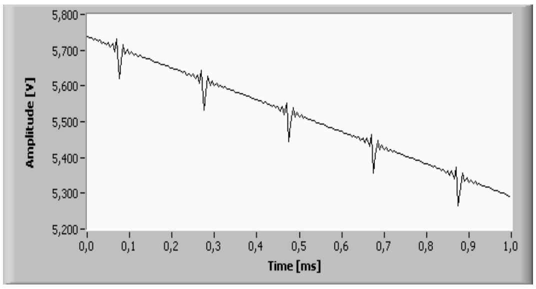

Fig.2 - 0.5 kV burst effect on a 9 V 10 Hz sinusoidal signal

Moreover, we observed that, simultaneously applying various EM threats, the effects of these disturbances combine in an approximately linear way. Therefore, for whatever input signal, if it is known, it is possible to quantify the consequences produced by the actual EM conditions. It is clear that the more accurate and less expensive signal to use in order to perform the test is a 0 V DC signal.

It is enough, therefore, to close the measurement chain in short circuit and, by means of a time and/or frequency analysis, we can easily evaluate if, considering the target uncertainty, the real EM disturbances can distort the measurement results. If possible, better results can be obtained closing the measurement chain in an impedance equal to the one of measurement point.

In the cases of steady disturbances and if their effects are not within the bandwidth of interest, it is possible to implement, into the software part of the instruments, algorithms to compensate for the disturbance effects.

IV. Practical cases

In order to validate the proposed approach, we performed various measurements in locations where heavy, but unkown, EM disturbances were present.

Let us consider the AI 16XE10-50 DAQ inserted in the notebook with a not-shielded configuration operating in the nearness of a voltage source inverter working in steady conditions.

By means of this DAS, we build a instrument for DC, RMS and THD value measurement of a distorted 50 Hz voltage signal with the characteristics reported in column II of tab. II.

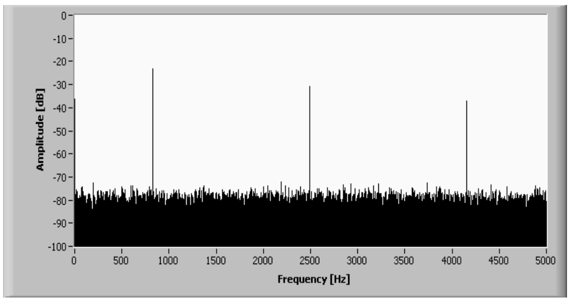

Fig.3. Frequency analysis with short circuited measurement chain in the nearness of the voltage source inverter

The signal is generated by the Agilent™ 33120A. The measurement is performed in differential mode, setting the gain to 1, sampling at 100 KS/s and choosing a 100 ms time window.

Before performing the measurements, we short circuited the measurement chain and we performed a frequency analysis, which is reported in fig.3.

The analysis show that the inverter is producing a visible interference with the DAS, generating a 15.5 mV DC component; a 831 Hz component and its III and V order harmonics.

For the measurement at issue, these components will not alter the measured THD value, but will alter the measured RMS and DC value. Performing the measurement, in fact, we get the values reported in column III of tab. II (all the reported values are the means of 50 measurements).

Filtering the disturbance components and subtracting the DC value measured during the test, it is possible to correct the results, obtaining the data reported in column IV of tab. II.

TABLE II. Mean values of the measures performed in the nearness of the voltage inverter

	II	III	IV	V	VI
DC value (V)	0.1000	0.1157	0.1001	0.1003	0.1002
RMS value (V)	6.3902	6.3912	6.3902	6.3903	6.3901
THD %	8.96	8.96	8.96	8.96	8.96

In order to validate the used approach, we repeated the measurement turning off the voltage inverter, obtaining the values reported in column V of tab. II.
For this measurement, therefore, the impact of the voltage source inverter can be practically removed by implementing the appropriate compensation algorithm and the DAS can be safely used even with a not-shielded configuration.
Repeating the measurement with a full shielded configuration and without the compensation algorithm, the inverter impact is almost completely negligible; in fact we obtained the value reported in column VI of tab. II.
The results obtained with the last experiment ensure that the EM disturbance has no effect on the signal generator.
We repeated the same measurement in the proximity of a 15 KVA welding machine. Before performing the measurements, we short circuited the measurement chain and we carried out a time and frequency analysis, which are respectively reported in fig.4 and in fig.5.

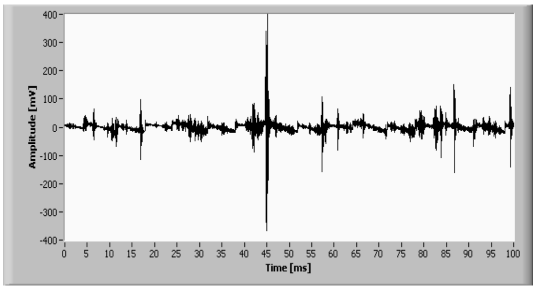

Fig.4. Time analysis with short circuited measurement chain in the nearness of the welding machine

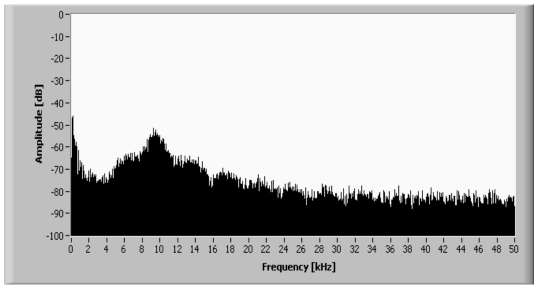

Fig.5. Frequency analysis with short circuited measurement chain in the nearness of the welding machine

In this case, the EM disturbance produces a heavy and not steady interference with the DAS and therefore the repeatability of the measurement get worse. Moreover, the disturbance effect occupies the bandwidth of interest and therefore, in these EM environment conditions, it is not possible to correct the disturbance impact. In table III the mean values and the standard deviations of 50 measurements are reported. The same measurement was performed by using a full shielded configuration and, in this case, the impact of the EM disturbance, even if still observable, is greatly reduced (table IV).
In this case, even though it is not possible to correct the disturbance effects and even though the EM disturbance is quite heavy, a good shielding allows a correct employment of the DAS. Also the not-shielded configuration can be used if the uncertainty target is compatible with the uncertainty enhancement caused by the EM threat.

TABLE III. Mean values and standard deviations of the measures performed in the nearness of the welding machine using the not-shielded configuration

Measure	"True" value	Mean value	Standard deviation
DC value [V]	0.1000	0.1722	0.0700
RMS value [V]	6.3902	6.3976	0.0220
THD %	8.96	9.04	0.12

TABLE IV. Mean values and standard deviations of the measures performed in the nearness of the welding machine using the full shielded configuration

Measure	"True" value	Mean value	Standard deviation
DC value [V]	0.1000	0.1070	0.0020
RMS value [V]	6.3902	6.3909	0.0010
THD %	8.96	8.98	0.01

The proposed approach can be easily extended to more complex measurement chains, such as when transducers and signal conditioning accessories are connected to a DAS. Also in these cases, after having closed the measurement chain in short circuit, a time and/or frequency analysis allows to evaluate if and how much the actual EM disturbances can distort the measurement results.
For instance, let us consider the same DAS used in the previous examples. In order to perform the RMS measurement of a 230 V 50 Hz feed voltage in an industrial location where various welding machines and other metallurgic devices were operating, we connected to the DAS the differential high voltage probe Tektronics^{TM} P5200 through an ad-hoc built IV order antialias filter with a 4 kHz cut-off frequency. The measurement is performed in differential mode, setting the probe attenuation ratio to 50 and the DAQ gain to 1, sampling at 10 KS/s and choosing a 1 s time window. Let the standard uncertainty target be 0.5 %. Without EM disturbances, the instrument is safely capable to achieve this uncertainty. In order to evaluate the disturbance impact, before performing the measurements, we short circuited the measurement chain and we carried out a time and frequency analysis, which are respectively reported in fig.6 and in fig.7.

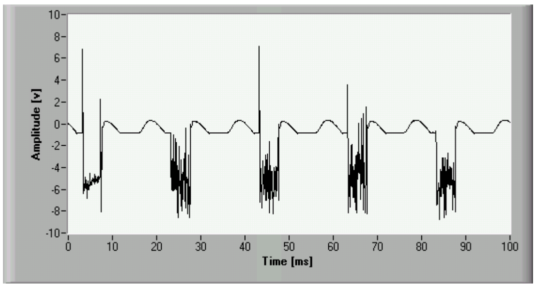

Fig.6. Time analysis with probe and short circuited measurement chain

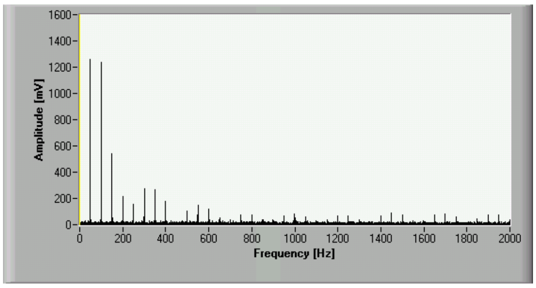

Fig.7. Frequency analysis with probe and short circuited measurement chain

The EM disturbances produce a heavy interference with the measurement instrument, which causes a 2.4 V RMS noise; since their effects occupy the bandwidth of interest of the measurement at issue, it is not possible to correct the disturbance impact. As a consequence, in the described EM environment the uncertainty target cannot be reached.

V. Conclusion

In the paper we tested the EM susceptibility of a generic PC-based DAS, subjecting various instrument configurations to the disturbances prescribed by the IEC-61236 standard. The results show that only the heavy disturbance levels cause a perceptible degradation of the instrument performances.
Starting from the experimental results, we proposed a simple and fast procedure to asses the actual impact of EM disturbances on a DAS. By means of this approach, it is possible to quantify the DASs interference with the EM environment and, therefore, to decide if the actual shielding conditions are adequate for the measurement purposes.
The procedure, moreover, allows the measurement correction when the measurand typology is known and the disturbance effects are steady and not within the bandwidth of interest.

References

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