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Electromagnetic compatibility analysis of electric equipments

***Abstract**. Electromagnetic compatibility- EMC and functional safety can no longer be treated as two separate disciplines when electrical or electronic systems are considered performing safety-related functions. Furthermore the usual EMC approach to define immunity requirements on the basis of availability and economical conditions cannot be applied to immunity issues regarding safety-related systems. And on the other hand the approach within functional safety to emphasize the relevance of the SIL cannot be transferred in a simple way into the EMC area. An appropriate approach to combine both disciplines consists of the introduction of special immunity levels and test methods in connection with a particular performance criterion "Functional Safety".*

***Streszczenie.** Analizowano łącznie dwa parametry – kompatybilność elektromagnetyczną i funkcjonalne bezpieczeństwo. Zaproponowano metodę łączenia tych dwóch parametrów z uwzględnieniem aspektów ekonomicznych. (**Analiza kompatybilności elektromagnetycznej i funkcjonalnego bezpieczeństwa w sprzęcie elektrycznym**)*

Keywords: reliability, electromagnetic compatibility - EMC, electromagnetic field, ISDN modem.
Słowa kluczowe: kompatybilnośc elektromagnetyczna, bezpieczeństwo funkcjonalne

Introduction

Reliable operation of electronic equipment at various technological and operation conditions requires safe operation on communication devices. Information transfer, automatic processing and data recording is exposed to detrimental influences from various sources. Disturbance effect of environments shows unwanted bonds, interference noise, resonance and transitional phenomena that may cause incorrect operation of electronic equipment, distortion and degradation of data transfer and its recording and in extreme cases also a destruction of the equipment.

At failure, e.g. as a result of shift or interturn short-circuit at the winding of a transformer; the electromagnetic interference with other electrical equipments may change [9], [10].

A system that is perfectly reliable but not electromagnetically compatible has no practical use [1], [2]. Equipment has to work in electromagnetic environment without breaching values set by technical standards and recommendations of CENELCC and IEC. Reliability and electromagnetic compatibility are inseparable requirements on system that is to operate reliably and to maintain its functionality. Factors of reliability must be monitored which in turn allows us using objective methods of reliability evaluation.

The theory of Electromagnetic Compatibility - EMC

Electromagnetic equipment is an emitter of electromagnetic disturbances and also a receiver operating in certain electromagnetic environment.

The basic of studying EMC of biologic and technical systems represents The Basic EMC Chain, depicted in Fig.1.

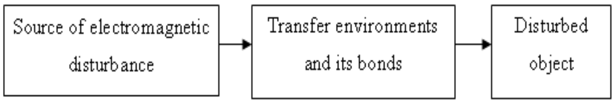

Fig.1 Basic EMC Chain

Disturbance generated by the equipment itself is measured according to a methodology described in the technical standard, expressed in [dBm]. Its relation to frequency is shown in Fig.2.

The limit of emittance resistance is the maximum permissible (i.e. allowed by the technical standard) limit of emittance of a particular equipment.

The difference between the limit of emittance and the level of emittance represents a reserve of design of particular equipment from the point of view of EMI. The level of resistance is the maximum level of disturbance affecting particular equipment at which the operation is not worsened. The limit of resistance is the lowest permissible level (according to the standards) of equipment resistance. The difference between these levels represents a reserve of design of particular equipment from the resistance point of view.

The difference between resistance and emittance defines the EMC reserve of particular equipment. The technical standards defines the term of compatible levels as a maximum permissible level of total disturbance that is believed affect equipment and devices operating in particular conditions. Differences between the emittance and the resistance towards this compatible level define the reserve of emittance and a reserve (span) of resistance.

If tested equipment is to comply with the EMC requirements, its level of emittance must be always lower than the maximum permissible level. The level of resistance must be always higher than the maximum permissible level. The limit of resistance must be higher than the limit of emittance. Only this way a sufficient reserve of EMC of equipment can be achieved. Actual value of the reserve of the equipment design from the EMI and EMC points of view is not defined in technical standards and can be set by the manufacturer with or without consideration of customer requirements.

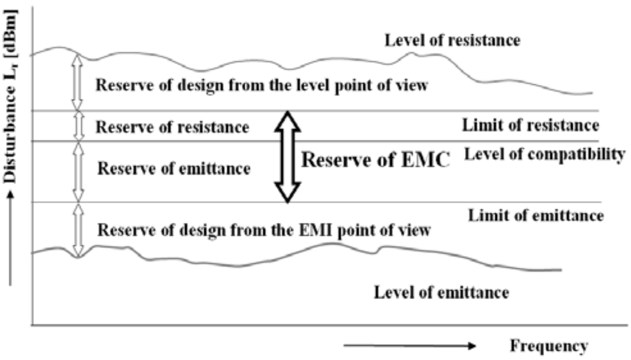

Fig.2 Frequency Related Compatible Levels of Disturbances

The theory Analysis of Interference Bond Mechanisms

The source of electromagnetic waves of required frequency is an oscillating circle. The reason for this is a fact that each moving electric charge with acceleration emits to its surrounding electromagnetic energy.

After closing a circuit with a charge capacitor current oscillations are formed and defined by function

(1) $I = I_0 \sin \omega t$

where the radial frequency ω is defined by Thompson equation

(2) $\omega = \left(\frac{1}{LC} \right)^{1/2}$

Electric charge (*q*) moving with acceleration (*a*) emits into its surrounding electromagnetic energy of intensity

(3) $W = \frac{2}{3} \frac{\mu_0 q^2 a^2}{4\pi c}$

Electric dipole with a dipole momentum *p* emits to its surrounding electromagnetic radiation of intensity

(4) $W = \frac{2}{3} \cdot \frac{\mu_0 p^2}{4\pi c}$

where: $p = \frac{d^2 p}{dt^2}$

and after modification

(5) $\frac{d^2 I}{dt^2} + \omega^2 I = 0$

Solving equation (5) we get a result that can be shown in a form of a function

(6) $I = I_0 \sin(\omega t - \varphi)$

This function represents electromagnetic oscillations, which in the area between the capacitor plates cause alternating changes of vector *D* (induction of electric field) and *B* (induction of magnetic field, i.e. electromagnetic waves).

To analyze EM field most often means to determine in each point of space a vector of electric and magnetic intensity.

During signal processing devices operate on higher frequencies and use smaller parts and connections between them are closer. This means that dealing with interferences is becoming more urgent on electro-technical equipment that is to operate with required level of reliability.

Types of interferences are:

- galvanic (using a common conductor, e.g. common ground),
- capacity (parasitic capacitance between two conductive structures),
- inductive (magnetic inductance transfer),
- wave (combination of capacity and inductive interference on parallel conduction).

Field bonds could be divided according to the source of the frequency:

- electro-static fields (low frequencies),
- magnetic fields (low frequencies),
- electromagnetic fields (high frequencies in MHz orders).

Statistic modelling of probability in relation to electromagnetic phenomena

Actual probability curves for most of the EM phenomena is currently not sufficiently known or discovered. Detailed information is available only for a few situations (for example lightning protection or impulse surges). But at the same time, this knowledge are not entirely exact and are more or less a file of information about the phenomena itself and not as much about their portion how they affect the reliability of equipment.

For statistical modelling logic regression is chosen for it is favourably suitable for modelling risk probability of one or more variables (disturbance signal). It allows us to predict a risk of an event (e.g. failure) in relation with a defined variable. In real evaluation of EMC reliability it is necessary to chose disturbance signal as a variable.

In an unified laboratory measurement we studied effects of one failure unit on terminal reliability which is mathematically formulated by single-unit data file of random quantity X. Similarly a multiple-unit data file in this case defines a selection of random vector X = (X1, X2, ..., Xp) as shown in Fig.3. Its theoretical background is described in [7], [8]. Multi-unit data files were obtained as results from measurements of several (p) physical quantities on samples of the same type.

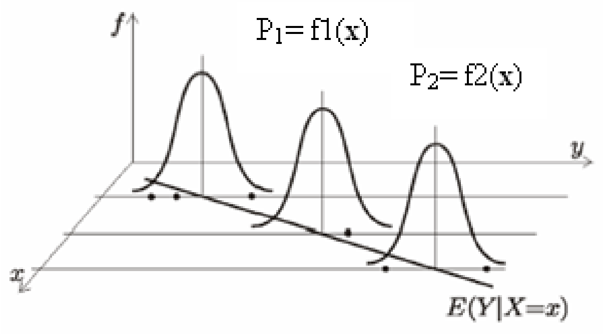

Fig.3 Relation of Y and X, Variations around the regression line represents the probability of a failure X as a result of disturbances

Measurements Analysis and Results Evaluation

Important factors affecting failure-free and reliable operation of a particular technological unit are the technical specifications of individual components. In order to verify correct operation of designed components for the technological unit (and its ability to function properly) that was designed by bearing in mind the theoretical knowledge in accordance with related technical standards and regulations, a real experimental verification was carried out. Using experimental methods equipment was monitored in its normal operating regime as well as in conditions where transitional phenomena occurred that is always a liability to any system with non-linear load. In order to achieve as close to perfect analysis as possible identification the whole system was analysed statically followed by dynamic analysis. To carry out such measurements suitable measuring apparatus had to be selected.

Measurement Apparatus and Evaluation Method Selection

The actual measurement was carried out by connecting an output disturbance voltage from the output of a sensor, its quantitative evaluation and comparison with emission limits of a testing object – environment. As long as the voltage being measured has a harmonic waveform it is possible for this measurement to connect a receiver working in a linear regime to which output clips an indicator is connected, e.g. low-frequency mV meter.

In practise we mostly deal with disturbance signals that have non-harmonic waveform and which frequency spectrum has non-harmonic segments. The quality of measurement is highly depends on measuring apparatus characteristics, on the range within the band to be analysed, behaviour of modulus-argument characteristics and their inter-comparability. The equipment to measure disturbance (spectrum analyzer HP 7402A, RFI Meter) is set as a special selective micro voltmeter working on superheterodynn principle.

Test of End ISDN Data Adapters

Layout of a testing plant equipped with measuring equipment is shown in Fig.4.

Fig.4. Layout of a testing plant equipped with measuring equipment

From the measured values a limit of resistance for TA ISDN adapter was set. Measured values were used as reference values for further analysis necessary for determining the level of reliability.

Measured values from test pieces had clear testimonial value i.e. from disrupting operational state of individual parts of the system up to complete loss of functionality of the whole system.

From the testing equipment we received a data file that helped to design parameters of resistance for test components and the suitability of their use in a particular industrial application. TA adapter was determined as the weakest link of the function chain. The detrimental effect was caused by link analogue ports. By applying overvoltage according to EN 61000-4-5 link ports were damaged but other data functions of TA remain operational.

Experimental measurements that were carried out and later evaluated contributed to increase of reliability especially in new control and communication system. [5].

Experimental EMI Measurements of Environment

While carrying out experimental analysis of reliability of electro-technical equipment in a particular environment it is necessary to compare measured values of EMI with the limit values set in technical standards, identification of disturbance frequency spectra and the level of disturbance intensity. The main point of this experimental measurement of EMI is to find the source of disturbance, thorough analysis and eventually elimination of unwanted parasitic bonds between the source and the receiver of disturbances.

Measurement of disturbance effects was divided into low-frequency and high-frequency, for which there are regulations and requirements for measuring methodology and measuring equipment. The source of disturbance produces disturbances that are transferred by conduction (line-in) and by radiation. To measure the conduction transfer an artificial mains was supplied and the measuring itself was carried out by using a voltage sensor and a current sensor. Measuring disturbances caused by radiation depends on homogeneity of close and distant electromagnetic fields. Distant electromagnetic field is characterised mostly by its mutual correlation of magnetic and electric part. This can be measured at the distance $r > \lambda/2\pi$ from the source of disturbance by means of dipole antennae. In closed electromagnetic field for which $r < \lambda/2\pi$ its electric part „$\overline{E}$“ is measured with an isotropic radiator and its magnetic part „$\overline{H}$“ is measured by using a frame antenna.

Measurements were carried out in selected locations according to the requirements of the investor in areas with suspected higher intensity of electromagnetic field – chiefly in high-current distribution stations [5].

Further measurements were carried out in control stations on all ISDN, measuring and control equipment responsible for reliable operation (Fig. 5 and 6).

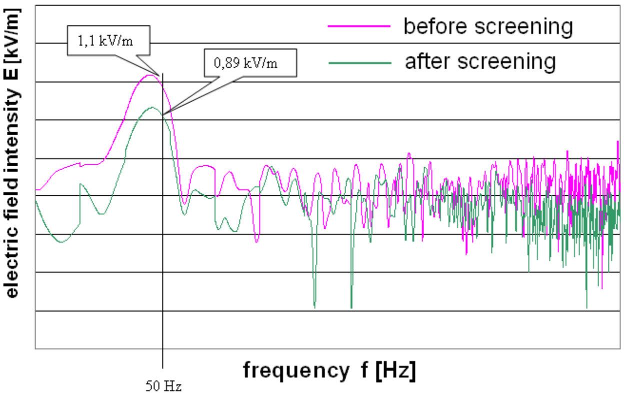

Fig.5. Electric part of electromagnetic field in vellum of control room

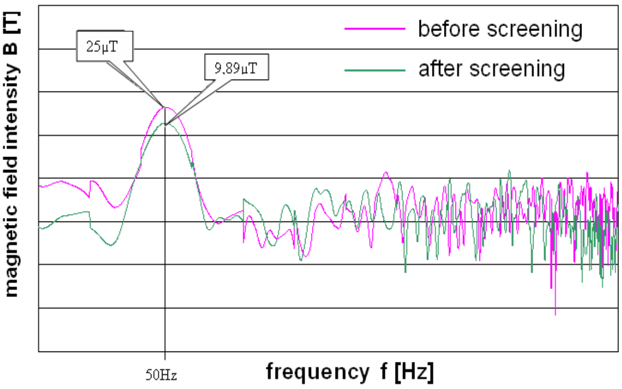

Fig. 6. Magnetic part of electromagnetic field in vellum of control room

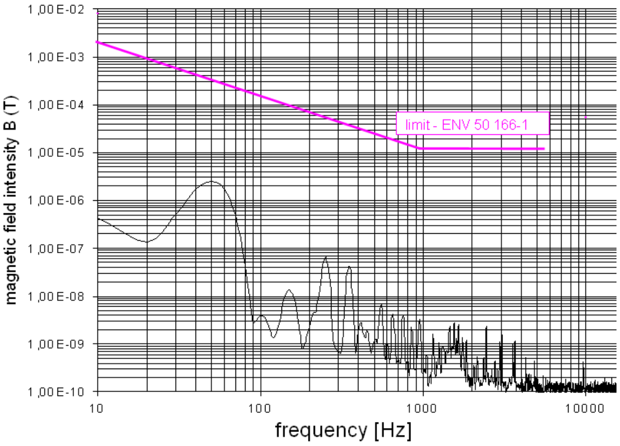

Fig. 7. Magnetic part of electromagnetic field with limit ENV 50 166-1

At the same time biocompatibility analysis was performed with the view of impact on service personnel working in these environments. Identified data file was mathematically processed by using FFT and the results were presented graphically into spectrally analysed area. Processed values that determined the behaviour of electromagnetic field were compared with the permissible values from technical standard ENV 50 166 – 1 (Fig. 7). From the analysis and evaluation of results real measures were taken that allowed reliable operation of sensitive electronic equipment against known clearly identified detrimental effects from the EMC point of view.

Conclusion

A real analysis of current state of selected end point telecommunication ISDN adapters were carried out from the EMC point of view.

The criteria of failure- free operation was chosen on the ground of presented means of carrying out the analysis with further evaluation that allowed us to clearly define in which function criteria A, B or C was the equipment able to perform its operation.

From the course of tests that were carried out on measured IT equipment we can clearly define failure-free operation of tested ISDN modem. Further analysis suggested measures to be taken that will enable almost total functionality of the particular equipment in the environment that we dealt with.

Performing a “complex” measurement of detrimental effects of electromagnetic field at the whole plant while respecting related technical standards and regulations, we can obtain an identification that gives us an unique testimonial value for each component and each area in which particular equipment is placed and operating but first of all the personnel working in those environments. The amount of data and knowledge acquired from both the theoretical study and in-site measurements gave numerous impetuses for further study. We believe that further study could lead to construction of a mathematical model of immune behaviour of larger technological units.

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