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The proposal of the laboratories for calibration of radar level gauges

***Abstract**. This article deals with the problem of the design of the measuring environment for the testing of the devices working on the base of the electromagnetic waves. We mean by these devices the radar level gauges. The radar level gauge is a source of the electromagnetic waves. The input part of this device receives reflected waves from the referential interface (reflection board). In the measuring environment can occur also various steel installations, e.g. constructions which consist of cylindrical steel beams. If the measuring environment contains steel installations, the receiving of the electromagnetic waves can be influenced by high frequency phenomena on the construction. In this article we focus on the proposal of the dimensions of the measuring environment.*

***Streszczenie.** Artykuł dotyczy problemu projektowania stanowiska pomiarowego do badania urządzeń wykorzystujących fale elektromagnetyczne. Pod pojęciem tych urządzeń rozumie się radarowe wskaźniki poziomu. Radarowy wskaźnik poziomu jest źródłem fal elektromagnetycznych. Wejściowy element tego urządzenia odbiera fale odbite od płaszczyzny odniesienia. W środowisku pomiarowym mogą występować różne instalacje stalowe, np. elementy konstrukcyjne złożone z cylindrycznych stalowych belek. Jeżeli środowisko pomiarowe zawiera stalowe instalacje, odbiór fal elektromagnetycznych może być zakłócany wskutek zachodzących zjawisk wysokoczęstotliwościowych. W artykule skupiono się na propozycji określenia wymiarów środowiska pomiarowego. (**Propozycja stanowiska laboratoryjnego do kalibracji radarowych wskaźników poziomu**).*

Keywords: radar level gauge, calibration, high-frequency electromagnetic wave, reflection, refraction, diffraction
Słowa kluczowe: radarowy wskaźnik poziomu, kalibracja, fala elektromagnetyczna wielkiej częstotliwości, odbicie, refrakcja, dyfrakcja.

Introduction

The radar level gauge is a very accurate device which measures the level of medium in the tank. It consists of two basic parts: a transmitter and a reciever. The receiver is composed of a directional antenna, an amplifier, an RF decoder, a circuit with the volltage comparator and a powerline circuit. The transmitter consists of a signal generator and a directional antenna (fig. 1). Work frequencies are 6, 8, 10, 24, 68 GHz. These level gauges are not sensitive to the changes of temperature, pressure, density and the composition of the gas in the measuring environment. The important condition of the measuring process is a correct response of the electromagnetic wave. These devices must be regularly calibrated. The process of calibration is carried out in the accredited laboratory. [3]

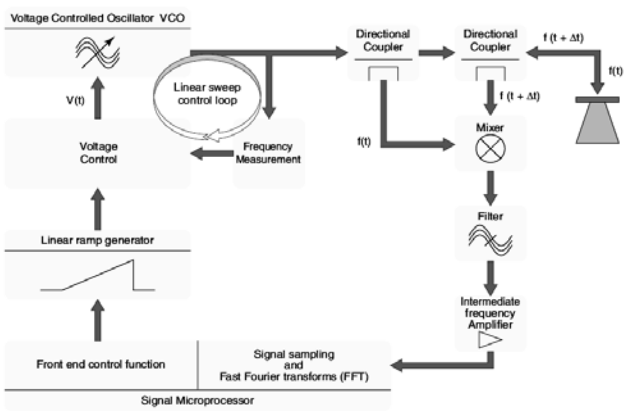

Fig. 1. Standard block diagram of FM-CW level gauge [2]

A. The typical construction of the laboratory

The laboratory for the calibration process of the radar level gauge must have adequate dimensions. The length of the laboratory must be minimal 16 m, because the calibration process is carried out for this distance. The height and the width are dependent on HPWB (*Half Power Beam Width*) of the antenna and work frequency of the level gauge. The steel beams which hold the metal guide rail are fixed under the ceiling of the laboratory. The reflection board moves on this metal guide rail. The measured distance is simulated by the moving of the reflection board. At one end of the laboratory is located a massive rack that holds the calibrated level gauge and the etalon of the length - the laser interferometer. Construction of this typical laboratory is shown in the figure 2.

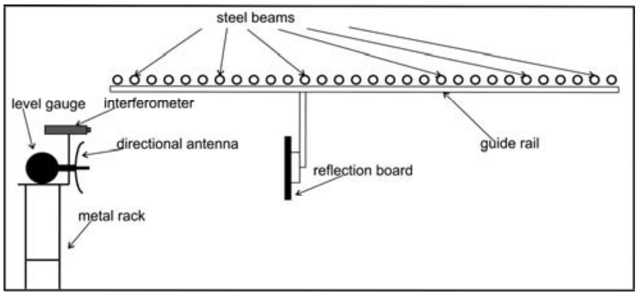

Fig. 2. Typical construction of the laboratory

Problem with dimensions of laboratory

The dimensions should be correct in the designing process of the laboratory. The process of calibration is carried out for the distance 16 m. Therefore we need length of the laboratory minimal *18 m*, because we need some service area for the metal rack, PC, etc. The next dimensions are dependent on the radar level gauge, respectively on its antenna and work frequency. Each antenna has parameter HPBW, which describes the angle of the radiation in degrees [1]. This parameter is dependent on the type of the antenna. The radar level gauge uses several types of antennas: cone, parabolic, still pipe, etc. HPBW can be 30° and also 3°. If we know this parameter, we can calculate, where the microwaves impact on the walls of the laboratory, respectively we can calculate minimal dimensions of the laboratory, where the disturbing effects cannot occur. The high and the width we determine by using following equation.

(1) $$x_{\min} = 2.d_{\max} tg(HPBW\ /2)$$

where: x_{min} - minimal dimension of height or width; d_{max} - maximal measured distance

If we create the laboratory with correct dimensions, transmitted electromagnetic waves should not be influenced by high frequency phenomena.

Nowadays in many cases we cannot create the new areas, but we must use which are done. These areas do not fulfil optimal dimension criteria. We need to know the high frequency phenomena what can occur by radiation with electromagnetic field of single parts of the laboratory. We know some high frequency effects: reflection, refraction and diffraction. In the introduction we wrote, that the radar level gauge is sensitive to correct response of electromagnetic waves. And those reflection, refraction and diffraction influence the correct response of the electromagnetic waves. The reflection is the formation by incidence primary electromagnetic wave with interface. The significant reflection can occur if the interface Fresnel criteria on the dimension fulfill [4]. For the better vision what shapes have the Fresnel's zone see figure 4. Minimal size of interface we can calculate by using (2)

$$b_1 = \sqrt{\frac{l_1 l_2 \lambda}{l_1 + l_2}} \tag{2}$$

where: b_1 – radius of the first Fresnel zone, respectively minimal radius of interface; λ – wavelength in free space area; l_1 – distance between the transmitter and interface, l_2 – distance between the receiver and interface (in our case are l_1 and l_2 same)

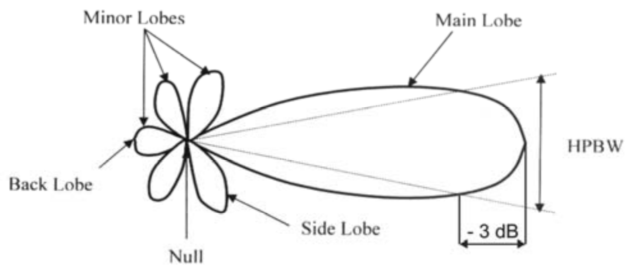

Fig. 3. Antenna radiation pattern

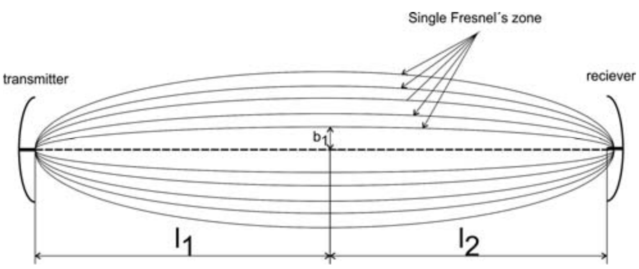

Fig. 4. Representation of Fresnel's zone

As we can see in (2), the radius of the first Fresnel zone is dependent on the distance from transmitter and the wave frequency. There also exists the refraction, in conjunction with the reflection. By incidence electromagnetic waves with the interface is the first part of energy reflected and the second part is transited to the second medium which is radiated. Ratio reflected and transited energy is dependent on permittivity ε of the second medium. The angle, which is between wave after transition through interface and its perpendicular, is angle of the refraction. In the figure 5 is angle of refraction β smaller than the angle of incidence α. This phenomenon is called the refraction to perpendicular. It is formed when the speed of the wave is in the second medium smaller than the speed in the first medium. [5]

If the electromagnetic wave impact on the barrier which is smaller than the first Fresnel zone, there do not form the reflection, but the diffraction. Diffraction is bending of the wave. If the size of the barrier is smaller than λ, then there is formed bending behind the barrier. The typical example of this type of barrier is steel beam, which hold the guide rail. Around the beam is the electromagnetic field significantly influenced by the diffraction. We can show analytical solution of this problem, see fig. 6.

The incident electric field can be written by [1] as

$$E_i = \hat{a}_z E_0 (-j)^n \varepsilon_n J_n(k\rho)\cos(n\Phi) \tag{3}$$

where: E_i – incident electric field; J – Bessel function; Φ – angle of observation point; ε_n – Neumann coefficient.

The total electric field around the conductive cylinder

$$E^t = E^i + E^s \tag{4}$$

where: E^i – incident electric field; E^t – incident electric field; E^s – incident electric field

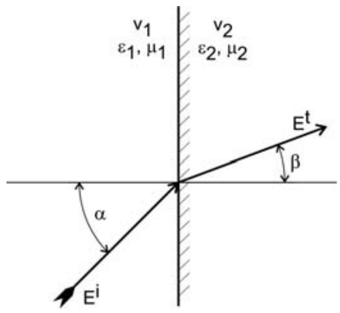

Fig. 5. Refraction

Since the scattered fields travel in the outward direction, they must be represented by cylindrical traveling wave functions. Thus we choose to represent E^s by [1]

$$E^s = -E_0 \sum_{n=0}^{\infty} (-j)^n \varepsilon_n \frac{J_n(ka)}{H_n^{(2)}(ka)} H_n^{(2)}(k\rho)\cos(n\Phi) \tag{5}$$

where: $H^{(2)}$ – Hankel function of second order; ρ – distance between source of E field and cylinder; k – wave number; a – radius of cylinder.

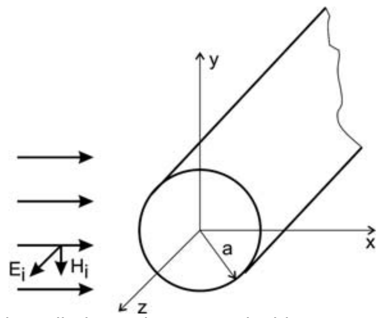

Fig. 6. Circular cylinder – plane wave incidence

Main results

In the previous chapter we analyzed which phenomena can occur if the dimensions of laboratory were not sufficient. Now we can calculate the minimal criteria which the environment must fulfill not to form the disturbing effects. The size of the height and the width are dependent on the type of the radar level gauge, respectively on the type of antenna which is used. On the base parameter HPBW we can calculate minimal dimensions of laboratory by using (1). In the figure 7 is shown functionality of the measured distance and the size of laboratory for single HPBW of level gauge's antenna.

If the laboratory does not satisfy these minimal dimensions, there can occur the disturbance effects. By incidence of the electromagnetic wave to electrical big barrier is formed reflection. Significant reflection can observed if size of the barrier is bigger than the first Fresnel zone. It´s size we can calculate by using (2). As we can see, the radius of the first Fresnel zone is dependent on frequency of electromagnetic wave and on distance between transmitter, respectively receiver and barrier. In the figure 8 are shown results of barrier's size for single frequencies.

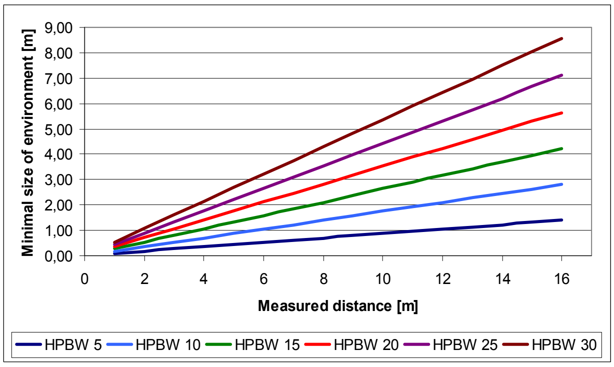

Fig. 7. Minimal dimensions of laboratory with consider of antenna's HPBW

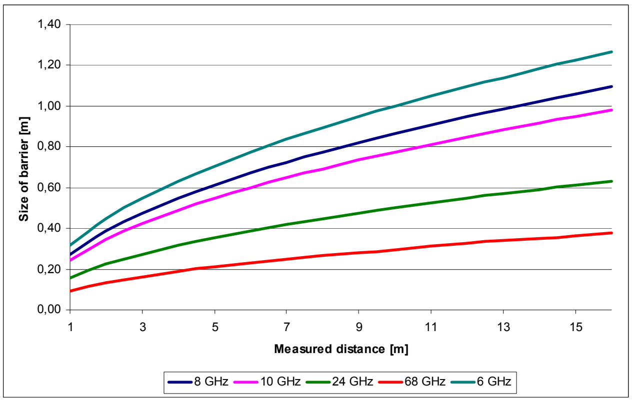

Fig. 8. Size of barrier depended on frequency of level gauge

On the graph we can see, that the electromagnetic wave is not reflected from small barriers as door handle, steel beams, guide rail, etc. Significant reflection can occur on the reflection board and on the walls. The most used construction element is steel beam. Analytical calculation of the electric field around the conductive cylinder is shown in chapter 2. The graphical output of this calculation is shown in the figure 9. This graph we obtained as a sum of the results from (5) and (3), where single parameter has next values:

a = 30 mm; k = 0.0299 rad.m^{-1}; ρ = 300 mm; Φ = 0 to *2π rad*

The value *ρ = 300 mm* is only for example. In the real condition is distance ρ larger.

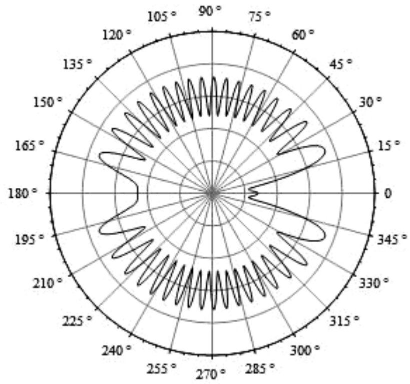

Fig. 9. Electric field around steel beam

Next we subscribe the typical construction of laboratory for level gauges testing. In the second chapter we solved the problem of proposal of the correct dimensions of the laboratory. These dimensions are dependent on the type of used antenna of the level gauge. If is height and width of the laboratory adequate there do not occur disturbances effects. In other case, there are form reflections on the barrier with the sufficient size. The size of barriers is dependent on the frequency of the radar level gauge. We calculated its dimensions for single typical used frequencies. The diffractions are formed around small barriers. The results of this article can be used for the design of the new laboratories for radar level gauges calibration.

Conclusion

In this paper we focus on the specifications of the single high frequency phenomena which can occur in the laboratory in the process of calibration of radar level gauges. These measures are very precise and therefore we need laboratory which do not influenced measured value. In the introduction we wrote the basic information about the radar level gauges, its basic parts and block diagram.

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