Influence of the Environment on the Accuracy of Measurement with Radar Level Gauges

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Abstract. *This article deals with the problem of the influence of the measuring environment on the accuracy of measurement devices working on the base of the electromagnetic waves. In the measuring environment can occur various steel installations, e.g. constructions which consist of cylindrical steel beams. The radar level gauge is a source of the electromagnetic waves. The input part of the radar level gauge receives reflected waves from the reference interface (reflection board). 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 analytical calculation of the electric field around the steel beam.*

Keywords: Diffraction, Steel Beam, Electromagnetic Field, Radar Level Gauge

1. Introduction

The radar level gauge is a device which measures the distance by using radar technique. It consists of two basic parts: a transmitter and a reciever. The transmitter consists of a signal generator and a parabolical antenna. The receiver is composed of a parabolical antenna, an amplifier, a RF decoder, a circuit with the volltage comparator and a powerline circuit. The worked frequency of the electromagnetic wave is about *10 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. [1]

The construction of the laboratory

The laboratory for the calibration process of the radar level gauge has given dimensions *16x2,6x1,9 m*. The steel beams which hold the metal guide rail (*2.20 m* high) are fixed under the ceiling of this environment. On this metal guide rail moves the reflection board. By moving of the reflection board simulates measured distance. At one end of the hall is located a massive rack that holds the calibrated level gauge of *1.35 m* above the floor and the etalon of the length - the laser interferometer. In the process of calibration can occur several disturbances. Unless unlimited space is available, there can appear the disturbing effects. The radiation angle of level gauge is *10°* and the steel beams are *0.85 m* distant. From these data we can calculate when steel beams will be irradiated. [1]

$$tg\alpha = \frac{d}{x} \Rightarrow x = \frac{d}{tg\alpha} = \frac{0.85}{tg5} = \frac{0.850}{0.088} = 9.7\,\text{m} \tag{1}$$

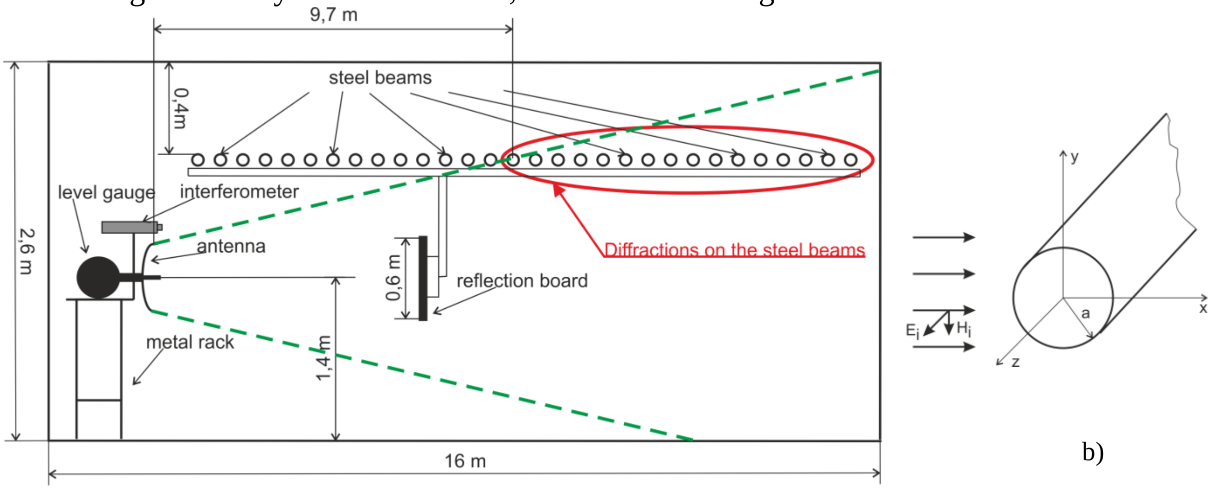
d – distance from the ceiling

α – the half of the radiation angle of the level gauge

The construction of this laboratory and the radiation angle of the level gauge are shown in the figure 1a. There are high frequency phenomena (diffraction) on the steel beams at a distance of about *9,7 m* in our conditions. It means that there will occur distortion of measured values if the measuring distance is longer than *9.7 m* . In this article we focus on the solution of the diffractions problem. We would calculate how is influenced the electric field around the steel beam by the diffraction. [1]

2. The diffractions on the steel beam

The steel beam has a cylinder shapes. The circular cylinder, because of its simplicity and its solution is represented in terms of well known and tabulated functions (such as Bessel and Hankel functions). Let us assume that a plane wave is normally incident upon a perfectly conducting circular cylinder of radius *a*, as it is shown in figure 1b.



a)

b)

Fig. 1. a) Construction of laboratory with radiation pattern of radar level gauge, b) Plane wave incident on conducting circular cylinder

The incident electric field can be written by [2] as

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

$$E_i = \hat{a}_z E_0 (-j)^n \varepsilon_n J_n(k\rho)\cos(n\Phi) \quad (2)$$

The total electric field around the conductive cylinder

E^i – incident electric field
E^t – incident electric field
E^s – incident electric field

$$E^t = E^i + E^s \quad (3)$$

where E^s is the scattered field. 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 [2]

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

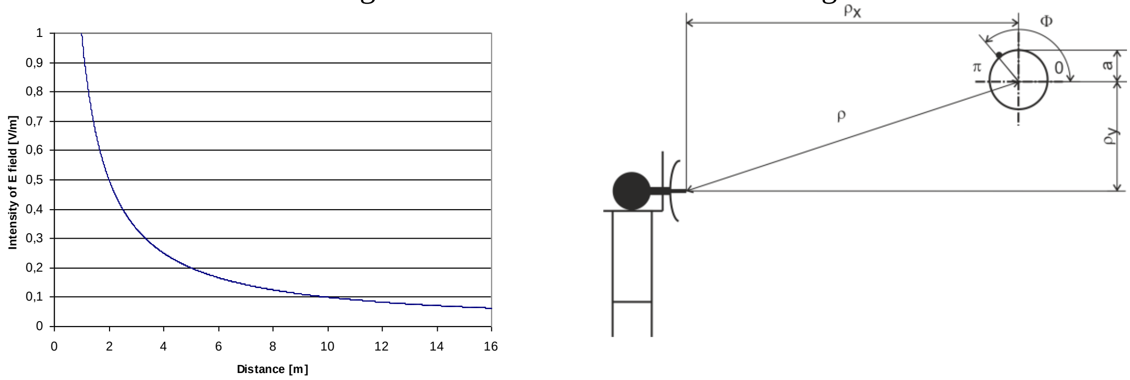
$$E^s = -E_0 \sum_{n=0}^{\infty} (-j)^n \varepsilon_n \frac{J_n(ka)}{H_n^{(2)}(ka)} H_n^{(2)}(k\rho)\cos(n\Phi) \quad (4)$$

3. The diffractions on the steel beam with decreasing of incident field

The solution of diffraction described in chapter 2 is correct, if the incident field is the same in the whole environment. We decided to solve this problem by using the decreasing incident field to ensure better results. Then the incident electric field can be written as

$$E^i = \hat{a}_z E_0 \frac{e^{-jk\rho}}{k\rho} \quad (5)$$

The curve of incident field along the environment is shown in the figure 2a.



a) b)

Fig. 2. a) Intensity of electric field along the environment, b) representation of distance the steel beams from level gauge ρ and radius of beam a

If the intensity of the electric field will decrease, it is clear, that the intensity of electric field on the steel beam surface with radius a will be variable too. In the solution is considered only distance ρ, which is described in the chapter 2. Now we calculate the distance for the individual points on the surface of steel beam by using formula (6). The individual dimensions are shown in the figure 2b.

ρ_x – distance between source of E field and cylinder in x axis
ρ_y – distance between source of E field and cylinder in y axis

$$\rho = \sqrt{\rho_x^2 + \rho_y^2} + a\cos\Phi \tag{6}$$

We apply the new proposal of calculating distance ρ to formula (5).

$$E^i = \hat{a}_z E_0 \frac{e^{-jk\rho}}{k\rho} = \hat{a}_z E_0 \frac{e^{-jk(\rho + a\cos\Phi)}}{k(\rho + a\cos\Phi)} \tag{7}$$

By editing the formula (7) step by step and then by using Bessel functions we can write the incident electric field in the form (8). Just this part of our solution is important. This is unique equation, which we made.

$$E^i = \hat{a}_z E_0 \frac{e^{-jk\rho}}{k\rho}\left[J_n(ka) - \frac{a}{\rho}\left[J_{n+1}(ka) - J_{n-1}(ka)\right]\right] \tag{8}$$

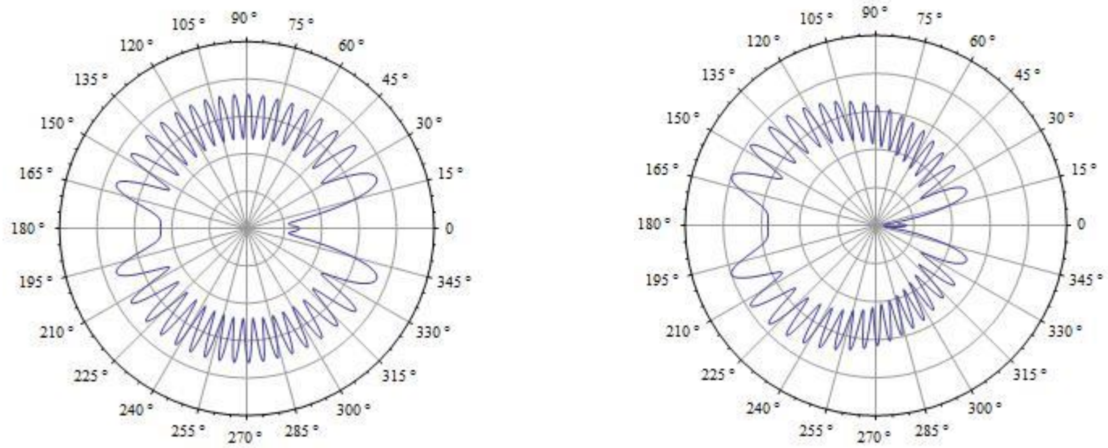
We can use formula (6) in the equation (4) similarly as in the previous case. We obtained the final form of equation for calculating scattered field around the steel beams in regard to decreasing incident electric field.

$$E^s = -E_0 \sum_{n=-\infty}^{\infty} j^{-n} \frac{J_n(ka) - j^{-(n-1)}\frac{a}{\rho}\left[J_{n+1}(ka) - J_{n-1}(ka)\right]}{H_n^{(2)}(ka)} H_n^{(2)}(k\rho) e^{jn\Phi} \tag{9}$$

For the comparison we made testing calculations. The results of our calculations we can see in the following chapter.

4. The results

For the comparison we calculated the total electric field around the steel beam with radius *6 cm* observed in distance 30 cm from surface of the beam. The total electric field is sum of incident and scattered electric field. The first results are obtained from formulas (2), (4) and they are shown in the figure 3a. The second results are obtained from formulas (8) and (9). There are shown in the figure 3b.



a) b)

Fig. 3. Total electric field around the steel beam a) constant incident electric field, b) decreased incident electric field

As you can see in the pictures, the differences between the first and the second solutions are significant. In the second solution the total electric field is shifted to the left, so the intensity of electric field is higher in front of the beam. In this direction it is also the receiving part of the level gauge. By using both solutions, which are described in the chapter 3, we can obtain more accurate values of the total electric field.

5. Conclusion

In our research we focus on solutions more high frequency phenomena which can occur in the process of calibration of the radar level gauges. The results are applicable in proposal process of accredited laboratory, which carry out calibrations or testing devices on the base of high frequency signals. In this article are presented results obtained by calculating total electric field around the steel beam. We considered constant and decrease incident electric field. The decrease field occurs in the real conditions. The solution, where we considered decrease electric field is very unique and it is our work. We find out the differences between the individual solutions. In the second solution we can obtain more accuracy values.

Acknowledgements

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References

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