gaining experience in installation of GSM-R,
- gaining experience in maintenance of trackside equipment ETCS,
- gaining experience in maintenance of equipment GSM-R,
- checking the ETCS level 2 equipment installed for PKP.
Section IV would serve the system tests, first of all rolling stock and level 1 equipment. As a target, also additional equipment of the section with level 2 ERTMS equipment. This section would enable the following:
- gaining experience in installation of trackside equipment ETCS level 1,
- gaining experience in maintenance of trackside equipment ETCS level 1,
- checking of ETCS level 1 equipment installed on PKP locomotives,
- checking of ETCS level 2 equipment installed on PKP locomotives (with exception of digital radio systems),
- checking of cooperation of various level ETCS systems installed on PKP locomotives with level 1 trackside equipment,
- this section could be also used for checking of ERTMS equipment installed on locomotives of other railway management locomotives.
Section IV should also fulfill the training role in ERTMS for PKP workers and other companies. This includes engineers of equipment, system installers, PKP personnel for commissioning of equipment, PKP equipment maintenance personnel as well as – to a certain degree – management of specific PKP units.

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OPTIMIZATION OF SELECTED RFID SYSTEM PARAMETERS
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Summary This paper describes procedure for maximization of RFID transponder read range. This is done by optimization of magnetic field intensity at transponder place and by optimization of antenna and transponder coils coupling factor. Results of this paper can be used for RFID with inductive loop, i.e. system working in near electromagnetic field.

1. INTRODUCTION
Basic RFID (Radio Frequency Identification) system consists of three parts:
- One or more identification transponders
- Reading device (reader), which enables communication between transponder and host system
- Data processing unit (microprocessor).

![Fig. 1. Basic principle of RFID system with inductive loop.](image)

Basic electromagnetic field parameters of RFID systems are in Fig. 2, where
- \( R_a \) is load resistance of transmitter’s antenna coil
- \( I_{aq} \) is transmitter’s antenna coil inductance
- \( C_a \) is serial resonant capacitance of transmitter’s antenna coil
- \( U_{aq} \) is voltage on transmitter’s antenna coil
- \( I_{aq} \) is transmitter’s antenna coil current
- \( R_{k} \) is loss resistance of transponder coil
- \( I_{k} \) is transponder coil inductance
- \( C_{k} \) is parallel resonant capacitance of transponder coil
- \( U_{k} \) is voltage on transponder coil
- \( I_{k} \) is transponder coil current
- \( R_{k} \) is parallel loss resistance of RFID chip
- \( k(x) \) is coupling factor between transponder and antenna coil

where \( L_a \) is antenna current, \( N_a \) is number of turns and \( x \) is distance from antenna in its axis direction.

![Fig. 3. Arrangement of circular loop antenna.](image)

Solving the equation (2), which is derivative of (1)

\[
dH(x) = \frac{I_{aq} N_a R_a^2}{2(x^2 + x_0^2)^{\frac{3}{2}}} [\text{Am}^2] \tag{1}
\]

we can compute that the maximum magnetic field intensity is reached when \( x = x_0 \), i.e. when the radius of reader’s antenna is approximately 41 % larger than required reading distance (Figs. 4 and 5).

![Fig. 2. Parameters of inductive loop RFID system.](image)

Next analysis deals with maximization of read range, i.e. how
- to determine conditions under which the reader antenna raduated energy is maximum
- to determine conditions under which the voltage induced from reader antenna coil to transponder coil is maximum, or, when the coupling factor \( k(x) \) is maximum.

2. MAGNETIC FIELD INTENSITY OF READER ANTENNA COIL
If the energy and data transfer proceeds in frequency range up to 30 MHz (wavelength more than 10 m), the RFID system works with inductive coupling in near electromagnetic field. Near electromagnetic field lies at distance up to \( \lambda/2 \) from its source (where \( \lambda \) is wavelength). Usually, the near field is being created by circular loop antenna with winding several numbers of turns with radius \( r_k \). The reader’s antenna arranged according to Fig. 3. creates magnetic field with intensity

\[
H(x) = \frac{I_{aq} N_a R_a^2}{2(x^2 + x_0^2)^{\frac{3}{2}}} [\text{Am}^2] \tag{1}
\]

where \( I_{aq} \) is antenna current, \( N_a \) is number of turns and \( x \) is distance from antenna in its axis direction.

where \( L_a \) is antenna current, \( N_a \) is number of turns and \( x \) is distance from antenna in its axis direction.

\[
\frac{dH(x)}{dx} = \frac{I_{aq} N_a R_a^2}{2(x^2 + x_0^2)^{\frac{3}{2}}} - \frac{3I_{aq} N_a R_a^2}{2(x^2 + x_0^2)^{\frac{5}{2}}} = 0 \tag{2}
\]

we can compute that the maximum magnetic field intensity is reached when \( r_k = x_0 \), i.e. when the radius of reader’s antenna is approximately 41 % larger than required reading distance (Figs. 4 and 5).

Magnetic field intensity can be increased by increasing of number of turns \( N_a \) and by increasing of current \( I_{aq} \). Fig. 2 shows that the reader’s antenna is serial resonant LC circuit with loss resistance, i.e. the current \( I_{aq} \) reaches maximum on resonant frequency

\[
f = \frac{1}{2 \pi \sqrt{L_a C_a}} \text{[Hz]} \tag{3}
\]
3. COUPLING FACTOR BETWEEN COILS

We assume that the coils are arranged according to Fig. 6, where:

- \( r_0 \) is radius of reader's antenna coil
- \( r_1 \) is radius of transponder coil
- \( \theta \) is angle between coils (0° parallel - 180° distance between coils.

In transponder coil place the magnetic induction \( B(x) \) and magnetic flux \( \Phi(x) \) are given by equations:

\[
\begin{align*}
R(x) &= \mu H(x) \\
\Phi(x) &= \pi r_1^2 B_1(x)
\end{align*}
\]

In transponder coil there is induced voltage \( U \) given by:

\[
U = N_r \frac{\partial \Phi(x)}{\partial t} = -N_r B(x) \pi r_1^2 \cos \theta
\]

The coils create a loss transformer, coils of whose is coupled by mutual inductance

\[
M = k(x) \sqrt{L_r L_t}
\]

Coupling factor \( k(x) \) is parameter which depends on geometrical dimensions of coils (Fig. 6) and is given by

\[
k(x) = \frac{r_1^2 r_2^2 \cos \theta}{\sqrt{r_1^2 + (r_2^2 + s)^2}}
\]

4. CONCLUSION

In this paper mathematical analysis of some of RFID system parameters is described. Results of analysis are valid only for RFID with inductive loop, i.e. when energy and data are transferred by magnetic field. In practice the working frequencies of such systems are 125 kHz (\( f_c = 2400 \) MHz) and 13.56 MHz (\( f_c = 22.12 \) MHz). If RFID system works on higher frequencies the electric field becomes dominant and theory described in this paper cannot be used. Moreover, results of analysis are not always practically usable. For example, if we require read range of transponder to be equal 1 m, distance of antenna and transponder coils should be 2.8 m. Such coils are very hard to realize, so only way to maximize the read range in such case is maximization of couple factor.

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Fig. 4. Dependence of magnetic field intensity \( H \) on coil radius \( r \). Current \( I=5 \) A, number of turns \( N_r=20 \).

Fig. 5. Dependence of magnetic field intensity \( H \) on distance from coil x. Current \( I=5 \) A, number of turns \( N_r=20 \).

Fig. 6. Arrangement of transponder and reader coils.

The coupling factor is basic parameter needed for correct RFID system operation. Theoretically, the system will work very well if \( k(x)=1 \), however it is unreachable in practice. For good system performance the sufficient value of \( k(x) \) is 0.01 (1%), in special cases the transponder is readable even if \( k(x)<0.001 \) (0.1%). Detailed analysis of (8) shows that:

- the angle between coils has to be 0°
- distance of coils have to be equal, in practice, the areas has to be equal
- distance \( x \) must be at minimum as possible.

Fig. 7. Dependence of coupling factor \( k(x) \) on distance x. Radius \( r_0=0.1 \) m, \( r_1=0.1 \) m, angle \( \theta=90° \).

Fig. 8. Arrangement of on-line mode measurement of partial discharges.

SOLVING SOME PROBLEMS WITH ON-LINE MODE MEASUREMENT OF PARTIAL DISCHARGES

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Summary

This paper deals with the problems discussing the transition from off-line diagnostic methods to on-line ones. Based on the experience with commercial partial discharge measuring equipment a new digital system for the evaluation of partial discharge measurement including software and hardware facilities has been developed at the Czech Technical University in Prague. Two expert systems work in this complex evaluating system: a rule-based expert system performs the online analysis of partial discharge impulses for determining the damage of the insulation system, and a neural network which is used for a phase analysis of partial discharge impulses to determine the kind of partial discharge activity. Problem of the elimination of disturbances is also discussed.

1. INTRODUCTION

Diagnostic methods are usually used for the determination of actual state of high voltage insulating systems, for the estimation of their residual lifetime, their behavior estimation and the risk assessment in the future operation (11) - (19). Diagnostics of high voltage insulating systems in off-line mode is worked sufficiently and it is broadly executed. However, both the price and power of the newly installed high voltage equipment in the power engineering branch grow up, and that is why the operator’s attention is focussed on the operational reliability of their equipment at first. The tendency of all operators is to monitor the state of their equipment continuously, i.e. using on-line methods.

However, the application of some 'classical' methods for on-line diagnostics is inappropriate, sometimes even impracticable (e.g. direct current methods, loss factor measurement, overvoltage tests). On the other means, new diagnostic methods are the observation of a discharge activity, which are usually based on the monitoring of secondary effects accompanying partial discharges (PD) in dielectric materials. One of these PD methods, applicable on high voltage grounded objects, is the galvanic method with parallel connection of the high voltage coupling capacitor and the measuring impedance with a lowpass filter. This method is broadly expanded due to its high sensitivity, a good resolution of individual types of PD impulses, and due to the fact that its using is not limited in the capacity of measured object or the quantity of used testing voltage. The advantage of this method is also in the possibility in using it directly during the machine operation by means of permanently installed probes.

2. PROBLEMS WITH ON-LINE MEASUREMENT

In the transition process from off-line diagnostics to on-line one (monitoring) it is not possible to take over original methodologies of the evaluation of diagnostic parameters 'automatically' (10). Some of diagnostic parameters of off-line diagnostics can not be measured in on-line diagnostics, some lose their sense and, on the other hand, it is necessary to develop new on-line diagnostic methodologies regarding of new conditions. For example, in an on-line PD measurement, the evaluation methodology is based on the dependence of basic diagnostic parameters (apparent charge, PD current, PD frequency) on applied testing voltage. In on-line measurement, the value of voltage is constant, but new dependencies appear, e.g. changes of basic diagnostic parameters in operational time. That is why it is necessary to develop new methodologies based on the monitoring of time shift of diagnostic parameters. Recently, some subjects about calibration process accuracy in the case of measurement of large capacity objects has appeared in technical community. As regards the evaluation of a diagnostic measurement, the quality of the evaluation and the reproducibility of results are stigmatized by relatively complicated methodologies and complicated (frequently artificially made) diagnostic parameters, what leads to the necessity of the consultation of top human experts for the high-quality evaluation. However, the complexity of the decision-making mechanisms (frequently on the edge of the intuitive decision-making) leads very often to the ambiguous or opposite evaluation of the actual state of the tested machine and estimation of its behavior in further operation. This practice is not acceptable for on-line diagnostics and it is one of reasons why it is not so reliable and why the on-line diagnostics is not so widespread these days. In connection with the on-line methodology development it is necessary to reduce a number of diagnostic parameters to the essential minimum, even at the cost of wasting partial information about the machine actual state. However, this disadvantage is entirely compensated by the fact that the changes in diagnostic parameters in an on-line measurement are indicated at once, and the damage evolution can be monitored permanently. The impossibility of using top human experts for the routine on-line evaluation because their temporary inaccessibility leads to the necessity of developing such an instrument which compensates the human expert view without decreasing the decision-making process quality. Expert systems based on the elements of the artificial intelligence are the best solution of this problem. Their knowledge bases containing experience of top specialists in the