EXPERIMENTAL EXAMINATIONS OF THE LOGISTICS PARAMETERS OF AN INDUCTIVE RADIO FREQUENCY IDENTIFICATION SYSTEMS

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Abstract

There are two main factors determining the applicability of an inductive radio frequency identification (RFID) system for dynamic operations: the logistics parameters (communication range, amount of transmittable data, communication time and speed of data carrier) and their effects on each other. The aim of the research of the Department of Building and Material Handling Machines, Technical University of Budapest, in cooperation with OMRON Electronics Hungary Ltd., is to develop a new measuring and analysing method to examine the logistics parameters mentioned above and to simulate their effects on each other. This method helps the end-users to choose the proper RFID system to be used in a given application, where RFID system will operate in dynamic conditions and the material-flow requires a lot of constantly changing information. This study gives a description of the research, its main steps, the executed examinations and their results. Furthermore, it indicates what additional tasks have to be executed to accomplish the research.

Keywords: radio frequency identification, RFID, data carrier, transponder, tag, reader, OMRON.

1. Introduction

The currently used low frequency, passive, inductive radio frequency identification (RFID) systems are operating based on the principle of the inductive coupling in near field region. Such systems constitute 90÷95% of the whole RFID market [7]. These RFID systems can be divided to two main parts: the only-read RFID systems and read/write ones. Nowadays, the read/write RFID systems are effectively applied for product identification and tracking in manufacturing, assembly and logistics processes, under which circumstances material flow requires a lot of constantly changing information and the RFID system operates under dynamic conditions, i.e. the data carrier (DC) passes by RF reader device (R/W head) during RF communication at the identification points.

The most important logistics parameters of such RFID system are:

- the *dynamic communication range*, wherein data can be transmitted between R/W head and DC,

- *amount of transmittable data*, which can be transmitted in the communication range while the DC is passing by the R/W head at a given distance from it,
- *communication time*, which is necessary for executing the transmission of a given amount of data between the DC and R/W head and
- *speed of the data carrier* during the communication process.

These logistics parameters determine which is the proper RFID system to be used in a given application under dynamic conditions.

The aim of the research of the Department of Building and Material Handling Machines, Technical University of Budapest, is to develop a new measuring and analysing method to examine the logistics parameters mentioned above and to simulate their effects on each other.

The following chapters will describe the main steps of the research in details: the principles of the relationships between the logistics parameters; the measurements and results of the static communication ranges of the examined OMRON RFID system; the measurements and results of the communication time functions; the presentation of a new measuring-system for determining the dynamic communication ranges; the results of the measurements compared with static ones and the further tasks of the research.

2. Principles of the Relationship between Logistics Parameters of an Inductive RFID System

The passive inductive read/write RFID systems consist of two main components: the moving part of the system is the data carrier (DC), which stores the data about the product to be identified; the static part of the system is the reader device (R/W head), which communicates with the DC by radio frequency based on inductive coupling (see *Fig. 1*).

The RFID system configuration, orientation of the antennas (coils) and the operating environment affect the shape and size of the communication range and the communication time process [10]. In this study we only examine the 'ideal' application of the RFID system. 'Ideal' is defined as having the operating environment ideal and the orientation of the coils in such a way that the DC's coil plane is parallel with the reader's coil plane and the coil centres of the RFID components are set at the same height ('ideal' orientation).

We intended to define the relationships between logistics parameters of an RFID system. Only when we know exactly the communication range, i.e. the width of the range at any DC distance from R/W head $(S(y_i))$ and communication time process $(T_c(N_j))$, we are able to answer the following questions:

1. What is the maximum usable DC speed ($v_{\max}$), where a given amount of data (N_j) between the R/W head and the DC in relation of the DC's distance from the R/W head (y_i) can be transmitted. We can calculate this by the next

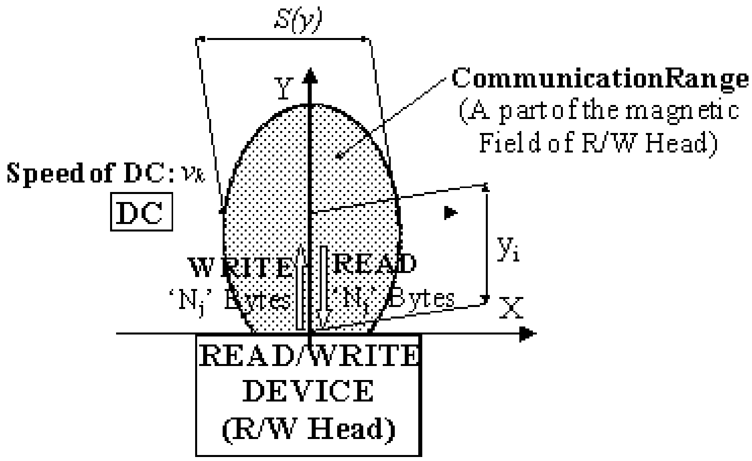

Fig. 1. Elements and logistics parameters of an RFID system

Eq. (1):

$$v_{\max}(N_j, y_i) = \frac{S(y_i)}{T_c(N_j)}. \tag{1}$$

2. How much data ($N_{\max}$) can be transmitted between the R/W head and the DC at a given DC speed (v_k) in relation to the DC's distance from the R/W head (y_i). This can be calculated by equation with iteration method (2):

$$T(y_i, v_k) = \frac{S(y_i)}{v_k} \leq T_c(N_{\max}) \Rightarrow N_{\max}. \tag{2}$$

3. What is the distance interval ($[y_{\min} \div y_{\max}]$), in which a given amount of data (N_j) can be transmitted at a given DC speed (v_k). The next computing method gives the results (3):

$$S(v_k, N_j) = v_k T_c(N_j) \leq S(y_i) \Rightarrow y_{\min} \div y_{\max}. \tag{3}$$

It is obvious based on the above said that the most important part of the research is to measure the communication range so that we can determine the function of $S(y_i)$ and to measure the communication time ($T_c(N_j)$) in relation of the data transmitted (N_j) for determining an estimated time function $\hat{T}_c(N_j)$ of the RFID system examined.

3. Main Steps of the Research

Fig. 2 shows the main steps of the research. The first step of the research was to choose of a passive inductive RFID system and to determine its configuration parameters. We selected the OMRON RFID system connecting to PLC with the following features [8]:

- V600-H06 read/write head operating under 530 kHz frequency. It was connected to an ID Controller Unit built in CQM1 PLC via serial port,
- V600-D2KR01 transponder with quadratic coil, SRAM memory and built-in battery.

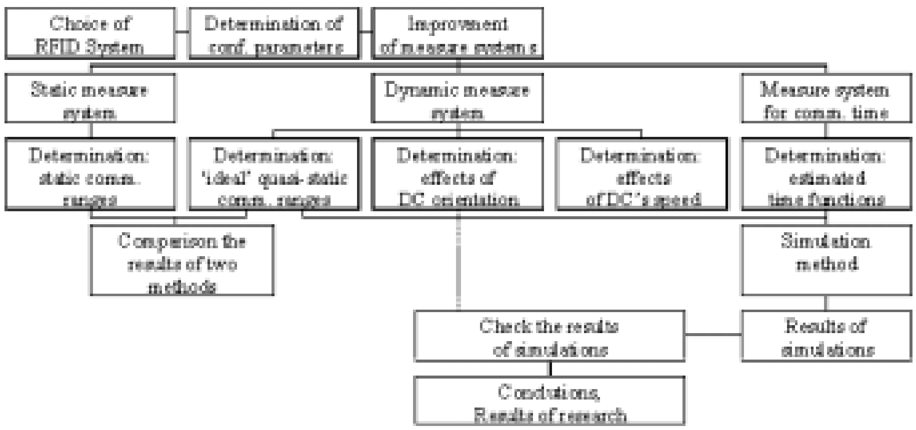

Fig. 2. Main steps of the research

3.1. Static Measuring System and Determination of Static Communication Ranges

Generally, an RFID system can be characterized by its static communication range. This range determines the communication range, wherein the R/W head can transmit the data to DC or receive from it, while the DC stands in front of the R/W head at defined positions (X, Y, Z coordinates) during the communication process. Two kinds of static communication ranges can be distinguished: read range, when data is read from DC and write range, when information is written to the DC from the PLC memory via R/W head [8] [9].

We developed a measuring system to measure these static communication ranges at the examined RFID system [9]. The DC was mounted on a microscope stage and its position could be set in X direction (and Z, but this value was always kept 0) and the R/W Head was fixed in the place of the microscope lens and its position could be adjusted in Y direction. The centre of the DC's coil related to the coil centre of the R/W Head could be adjusted with an accuracy of 0.01 mm by moving the microscope stage. At each measuring-point (x_j, y_i) we executed 10 ID communications.

Fig. 3 shows the result of the executed measurement belonging to static communication range of the reading process. The most important result of this measurement series is that there is no difference between reading and writing static communication ranges at the given RFID system.

Although these results re-enact the manufacturing data of the examined RFID system, they are not suitable to examine the relationships of the logistics parameters of an RFID system operating under dynamic conditions, since it does not take into account the effect of DC's loading process on the communication range under dynamic conditions.

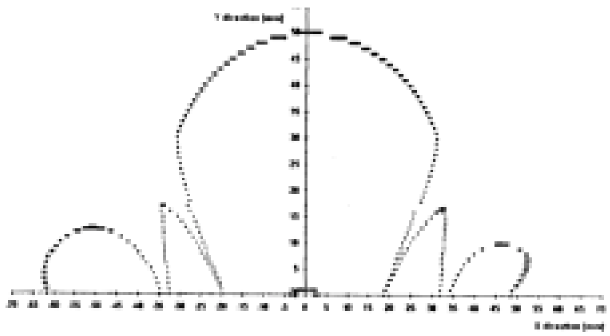

Fig. 3. Static communication range-reading

3.2. New Measuring System to Examine the Dynamic Communication Ranges of an RFID System and their Results

We had to develop a new measuring system to examine the dynamic communication ranges of an RFID system, which can provide more accurate results than the static measurements, due to the fact that the communication time process ($T_c(N_j)$) affects significantly the communication range.

The dynamic communication range determines the range, in which R/W head can transmit the data to DC (write) or receive from it (read), during the DC is passing by the R/W head at a given speed in the ID communication process(es). When the speed of the DC is the lowest according to the expected accuracy ($v_k = v_{\min}$) and the transmitted data is minimal ($N_j = N_{\min}$) (in our case: $v_{\min} = 0.025$ m/s, $N_j =$ 1 byte), then the communication range is defined as quasi-static communication range, in all other cases it is defined as dynamic communication range mentioned above [1],[2].

Although the orientation of the DC to the R/W head affects the shape and size of the dynamic communication range, in this study we examine only the 'ideal' orientation.

Fig. 4 shows the set-up of the new measuring system which is to determine the dynamic communication range of an RFID system connected to PLC. The DC is fixed on a console screwed on the plate of the $X - Y$ linear table. The R/W Head is fixed to the support of the $X - Y$ table. Interval of the DC's movement in X direction ($x_{\min}$, $x_{\max}$), distance of the DC from R/W Head in Y direction ($y_{\min}$, $y_{\max}$), the DC's speed (v_k), and the space in Y direction (Δy) can be optionally set.

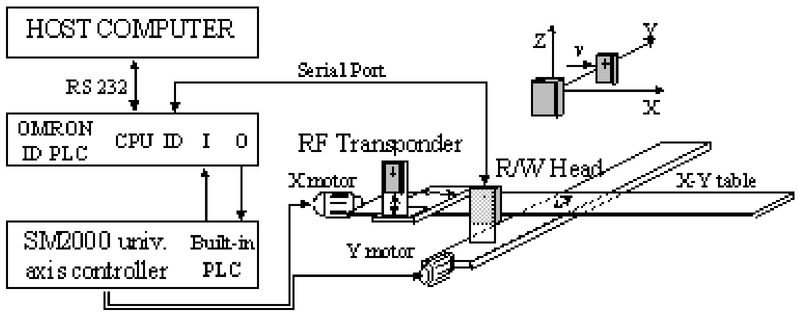

Fig. 4. Set-up of the new measuring system to examine the dynamic communication range

During the measurements the DC passes by the R/W head with an adjusted speed (v_k) and distance from R/W head, and we measured the communication distance ($S(y)$) and the amount of successfully executed ID communications, i.e the amount of maximal transmittable data inside this communication distance. We executed 10 measurements in each DC distance from R/W head between $y_{\min} \div y_{\max}$.

For analysing the dynamic communication range the communication time, the total elapsed time, the actual position of $X - Y$ table in X direction and the successful execution of ID instruction are measured at the completion of each ID communication during each measurement.

The measurements show that the 'ideal' read and write communication ranges of the RFID system are equivalent with each other in shape and size, as in the case of static measurements (see *Fig. 5*). If we compare these ranges with static ones, we can see that the dynamic ranges are asymmetrical to Y axis, i.e. the entering border is situated nearer to the Y axis, than the exit border. The cause of asymmetry is the behaviour of passive DC, because when the DC enters the RF field generated by the R/W head, it must receive sufficient energy to operate correctly, and only after that the communication with R/W head starts. This process is called loading process. The difference between entering and exit borders is given by the distance passed by the DC during the loading process.

Further advantage of this new measuring system is that we can directly examine the maximum amount of transmitted data ($N_{\max}$) as well during measurements. *Fig. 6* shows the result of the read measurement in 'ideal' orientation of the DC belonging to $N_{\max}$ in relation of DC distance from the R/W head. This measurement makes it possible to compare and verify the simulation results calculated by further developed analysis software with these measurement results [5],[6].

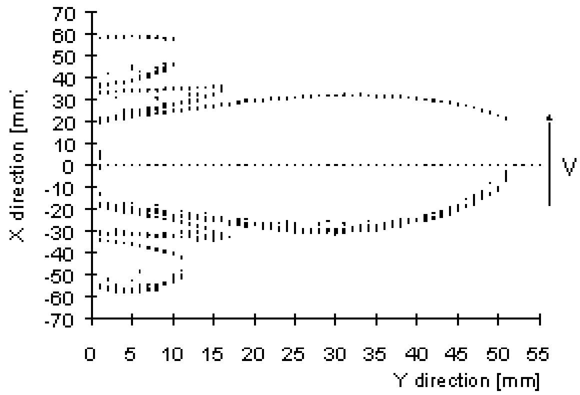

Fig. 5. Quasi-static communication range

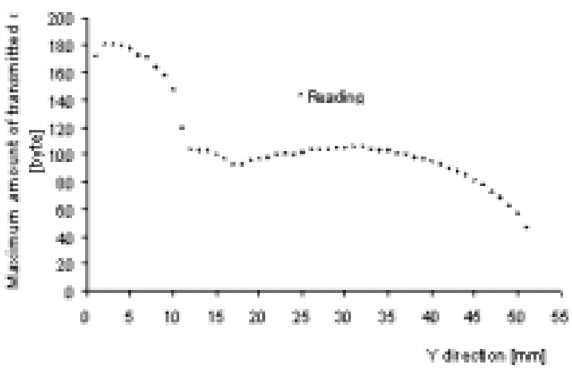

Fig. 6. Maximum data transmitted. Reading, $n_1 = 1$ byte

As a conclusion this new measuring system can be effectively applied to measure the quasi-static and dynamic communication ranges of an RFID system and to give the first logistics parameter for our analysing method.

3.3. Measurement of the Communication Time and Its Results

The aim of this measurement series is to measure the communication time ($t_c(n_l)$) depending on the amount of data to be transmitted per ID instruction (n_l), and to determine the estimated communication time function ($\hat{t}_c(n_l)$) as the basis for determining the second logistics parameter of the examined RFID system.

The communication time means the elapsed time from issue of an ID instruction from PLC to return of response signal from DC after finishing the communication. In general, the communication time needed for the writing process is longer than the communication time needed for reading process, and the more the transmitted data between DC and R/W head, the longer the communication time needed is. So we had to measure the communication time in relation to transmitted byte number at the given RFID system in case of reading and writing process as well.

During the measurements the R/W head and the DC were installed in a way, that the R/W head can surely communicate with the DC well ($y_i = 20$ mm, $x = z = 0$ mm). Each part of the measurement was executed in similar way. During the measurement the byte number ($n_l, l = 1 \div 256$) had to be adjusted first, after that data transmission and the measurement of the communication time were executed automatically 10 times. The measured data stored in a database give the input parameters for the evaluation of the measurement [4].

The following communication time functions can be shown on the basis of the average time values ($\bar{t}_i$) of 10 measurements at a given byte number (n_l) (see *Fig. 7*).

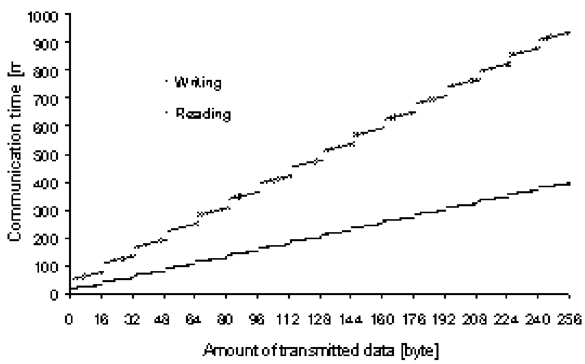

Fig. 7. Communication time – reading

3.4. Estimated Communication Time 'Functions'

The aim of the evaluation was to give mathematical estimation of the communication time functions according to the ID instructions on the basis of the measured data and to give an adequate evaluation method. These can be determined with the help of regression analysis. For each ID instruction a proper regression line can be given with the following formula ($n_l \leq 256$) (4):

$$t_c^{\mathrm{ID}^{**}}(n_l) = \overline{\hat{A}}^{\mathrm{ID}^{**}} n_l + (\hat{C}^{\mathrm{ID}^{**}} k + \beta^{\mathrm{ID}^{**}}), \tag{4}$$

where n_l amount of the transmitted bytes per ID instruction [byte],
k the serial number of the interval, under which the n_l byte falls [byte]; $k = \text{int} : [(n_l - 1)/16]$,
$\overline{\hat{A}}$ data transmission rate [ms/byte],
$\hat{C}$ verifying time of the transmission of every 16 bytes [ms],
$\hat{\beta}$ fix time – the time of the transmission of '0' byte [ms].

Table 1 shows the different values of the function parameters belonging to each ID instruction calculated:

Table 1. Function parameters of the estimated communication time

ID Instruction (ID**)	Data transm. rate $\overline{\hat{A}}$ [ms/byte]	Verifying time $\hat{\beta}$ [ms]	Fix time $\hat{C}$ [ms]
Writing process	1.6824	73.6998	30.2259
Reading process	0.8400	40.5119	10.6015

On the basis of this measurement series and the determined estimated time functions we can calculate the estimated communication time period ($\hat{T}_c(N_j)$) of a given amount of data (for $N_j > n_l^{\max}$ as well) by the formula (5):

$$\hat{T}_c^{\text{ID}^{**}}(N_j) = m^* \left[\hat{t}_c^{\text{ID}^{**}}(n_l) + T_g\right] + \hat{t}_{\text{rest}}^{\text{ID}^{**}}(z), \tag{5}$$

where N_j amount of the total transmitted bytes [byte],
n_l data package – the transmitted byte number per ID instructions [byte],
m amount of the executed ID instructions $m = \text{int}\ (N_j/n_l)$,
z amount of remaining bytes to be transmitted, $z = N_j - m$ [byte],
$\hat{t}_c(n_l)$ estimated communication time for transmitting a data package [ms],
T_g PLC cycle time [ms],
$\hat{t}_{\text{rest}}(z)$ estimated communication time for transmitting of the amount of remaining bytes [ms].

So the above gives the second logistics parameter, the estimated time function.

3.5. Other Executed Measurements

The new measuring system presented in chapter 3.2 is also suitable to measure two other effects at an RFID system operating under dynamic conditions:

1. Effects of DC's orientation to R/W head on dynamic communication range [5] [6] and
2. Effects of DC's speed (v_k) and transmitted data package ($n_l = 1 \div 256$) on the maximum amount of transmittable data.

In the frame of the first point we examined the effects of DC's orientation to R/W head on dynamic communication range in the following case (see *Fig. 8*):

- DC rotation to R/W head in Y direction,
- DC offset to R/W head in Z direction,
- DC rotation to R/W head in Z direction.

These measurements are taken into account when calculating the effects of the logistics parameters on each other by an analysing software to be developed as well. The aim of the second measurement series was to measure the maximum

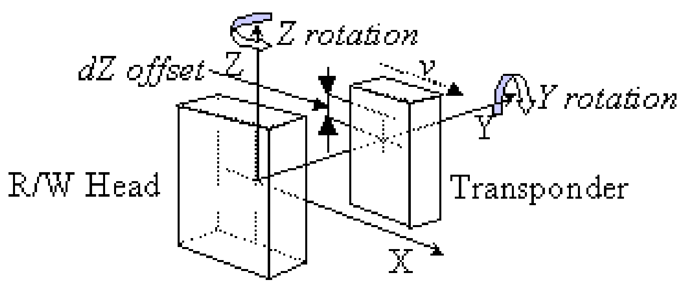

Fig. 8. Orientation of DC to R/W head

transmittable data depending on DC's speed ($v_k = 0.025$, 0.05, 0.075 and 0.1 m/s) and transmitted data packages ($n_l = 1$, 16, 32, 64, 128, 256 bytes) at 'ideal' DC orientation in case of reading and writing as well. The measurement results can be directly compared to the results of the simulation results executed by the analysing software to be developed.

3.6. *The Next Step of the Research*

The further step of the research is to develop a new analysing software to simulate the effects of the logistics parameters on each other. The software will provide the following analysing tools:

1. It can calculate the effects of the logistics parameters on each other (see chapter 2) under 'ideal' conditions based on the measured ideal dynamic communication range and estimated time function in case of read and write as well.
2. It can calculate the effects of DC's orientation on the logistics parameters taking into account the changing of the quasi-static communication range.

The advantage of the analysing software will be to give more information about logistics parameters and their effects on each other without execution of a lot of measurements. So the end-user gets more accurate data about the RFID systems for selecting the proper one to a given application and the choice becomes simpler and more effective.

4. Conclusion

The project results show that we are going in the right direction by developing a new measuring and analysing method for the examination of the logistics parameters of any inductive RFID system and their effects on each other.

The measurement results presented above provide the basis for the analysing software to be further developed to simulate the effects of the logistics parameters on each other and they can be matched against the simulation results.

In the frame of the research we developed a new measuring system (DYMS) to determine the dynamic communication ranges of an RFID system. The dynamic communication ranges differ from a static one, so it is necessary to use the DYMS to determine these ranges at the RFID systems working under dynamic conditions (DC moves during ID communication). The effects of DC's orientation to R/W head on logistics parameters can be examined with it as well. Further advantage of the DYMS is to make it possible to measure the amount of transmittable data at the same time.

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