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RFID technology in product lifecycle management

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1. Introduction

Most of the manufacturers have to comply with market changes and continuous shortening of the product life cycle. Changes on the factory floor are happening on a daily basis. In order to procure these changes production structures have to be more manageable by means of lowering degree of complexity and enabling production structures to adapt flexibility (Maksimovic et al., 2010). Also, there is a need for finding a good solution to the problem of production of certain types of products and their disposal into the waste dumps, in order to reduce and control the quantity of such waste, because the waste is being made in ever-increasing quantities (Ostojic et al., 2008).

In order to make product management more efficient during the whole life cycle (not only in production and assembly/disassembly phase), data collection about all kinds of flows of products, materials, parts/subassemblies and dangerous elements/materials is of crucial importance. Product monitoring during the whole life cycle provides:
  - natural resource exploit optimization and their deplete reduction,
  - product life cycle optimization (in the stage of early product life cycle phases - production, sales, services),
  - reduction of environmental pollution with the products that have come to an end of their life and work cycle (Stankovski et al., 2009a).

Improvement of production systems, especially assembly/disassembly subsystems (for refining the outdated product), and the management of all the above flows can be achieved by implementing RFID (Radio Frequency Identification) technologies. RFID technology is technology that can be implemented in industry (Vukelic et al., 2010) and non-industry conditions like education (Stankovski et al. 2009b, Ostojic et al., 2010). Information gathered in this way is reliable, precise and dynamic. RFID technology allows provisions for optimal management of products that have come to the end of their work lifetime (Stankovski et al., 2006).

In this chapter a strategies and strategy selection for products at the end of the life cycle are defined. Also, a model of RFID technology application in assembly/disassembly systems and other phases during the whole product life cycle is presented as well as the results of its implementation in a system for monitoring the status of an In-mould Labeling (IML) robot.

2. RFID Technology

RFID is a system for automated data acquisition which allows collection and wireless (radio wave) transfer of production- and business-related data. RFID technology is suitable for usage on plastic product/parts (Inkenzeller, 2003.). Since the moment, a product is manufactured, to the beginning of its exploitation or disassembly, RFID technology allows real-time identification, during delivery, storage, or any other process taking place within an enterprise. By means of radio waves, the data are acquisitioned and transferred in wireless mode between production and business processes in real time. This unique way of identification is adjusted in such a way that it allows the information on product to correspond to the information on the side of the company or the host system. Using RFID technology, it is possible to track products and equipment, with minimum human intervention. This can potentially cut back operating costs and increase real-time visibility during complete product life cycle.

RFID system consists of: a computer (or Programmable Logic Controller (PLC)), RFID reader, antenna (which can be integrated in a RFID reader) and transponder - tag (Fig. 1). The antenna is used to amplify the signal, which is emitted by the reader to the tag, as well as the signal, which is returned to the reader by the tag, which increases the tag-reading range. RFID reader can be a stationary or a portable device, which can activate and pick up the signals emitted by the tags. It consists of the power unit, antenna and a printed circuit board, and its primary role is to receive and send RF (Radio Frequency) signals to the tags by means of antenna. From a computer or a PLC, the reader receives instructions generated by the dedicated software. The control unit inside the reader executes the received instructions (Inkenzeller, 2003; Glover & Bhatt, 2006).

The readers differ by the range and operating frequency. Similar to the tags, the readers can have small range (up to several centimeters), medium range (up to 1 meter), and long range (tens of meters, with an additional antenna). Besides, there are readers equipped with potentiometer for range regulation (Glover & Bhatt, 2006).
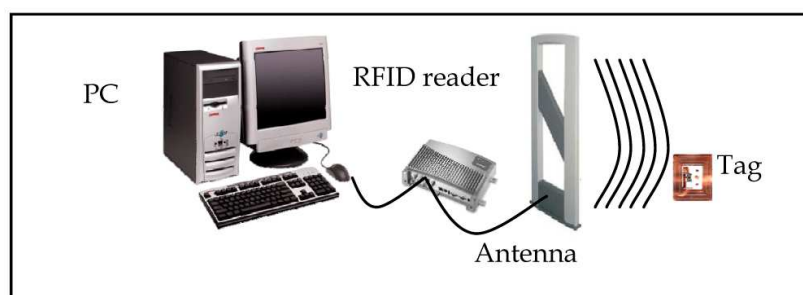

Fig. 1. Basic components of RFID system

The tags consist of a microchip (which stores alpha-numerical code for product labeling), an antenna (copper wire - coil) and an optional power source (e.g. battery). They exist in a variety of forms: various pendants, circular or square plates, magnetic cards, or some other form, depending on the area of application (Fig. 2). Smart labels are a special type of tags which can be placed on, or built into a palette or any sort of product.

Fig. 2. Various forms of RFID tags

The components of RFID systems are selected depending on the area of application. Of primary consequence is the operating frequency of the components (Fig. 3). In most of the countries, the operating frequencies for RFID systems are strictly defined.
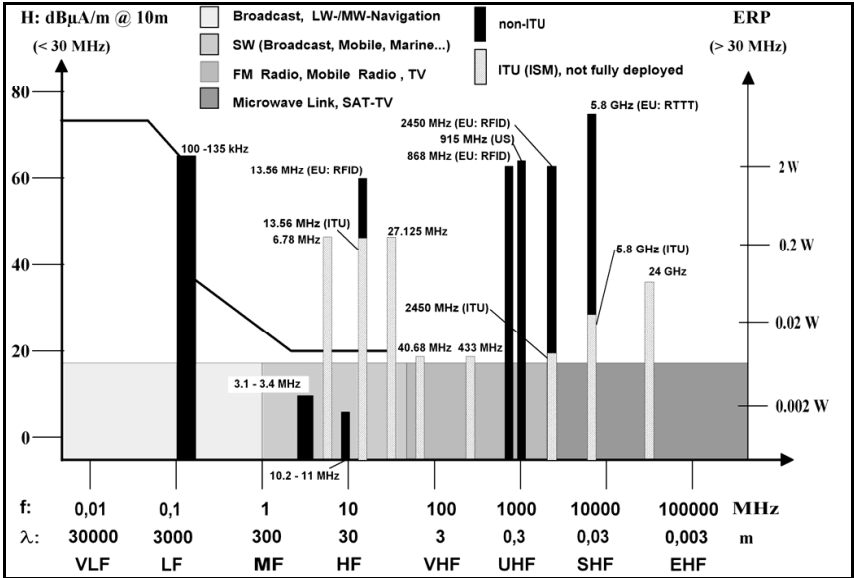

Fig. 3. Illustration showing the broad range of frequencies within the electromagnetic spectrum that RFID system can utilize

Once RFID tag enters reader's operating range, the reader detects its activation signal. The reader then decodes the data coded in tag's integrated circuit and the data is transferred to the computer for processing. Until now, for automated detection of products mostly bar code technology has been used, which had numerous deficiencies:

- Bar code reading requires an operator to manipulate product in order to be detected by the reader, or to manipulate the reader itself. This requires a number of workers;
- Bar code must not have any impurities, or otherwise the reading is erroneous. This is prohibitive in industrial environment where there are oil stains and other impurities;
- Bar code labels are often hard to place on palettes or products;
- Finally, the greatest deficiency of bar code is that, in case identification needs to be changed on a palette or product, new label must be used, which increases material consumption and requires additional time to finish the operation.

Significant advantage of RFID systems is that they do not require contact for proper functioning. Tags can be read in any industrial environment, which can involve snow, fog, ice, color stains, dirt and similar. RFID tags also read fast - in most cases the response is faster than 100 milliseconds. New generation of readers have ability to simultaneously read several tags. Thus whole storage area can be read at once instead of scanning each article individually (Shepard, 2005).

3. The System for Monitoring Products During Their Life Cycle

All phases of the product life cycle, starting from the first phase – production, following with distribution, sales, usage, service and maintenance to the phases coming at the end of the life cycle (disassembly, recycling, reassembly, incineration, waste disposal) is presented in Fig 4. It is important to emphasize that not every, but most of the products pass through the mentioned phases during their life cycle.
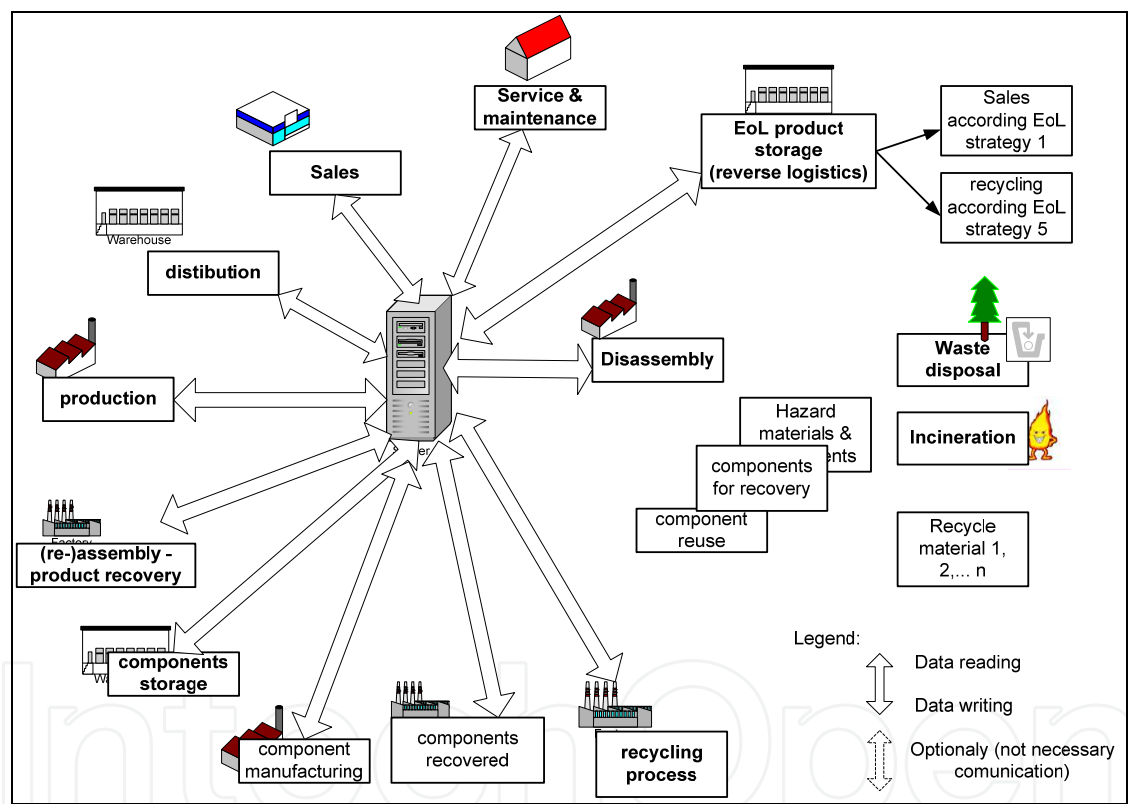

Fig. 4. Phases of product life (Stankovski et al., 2009a)

Disassembly is just one of the processes in the life cycle of a product and lately it has attracted a lot of attention, considering its key role in reassembling and recycling of products. This is due to ecological and economical reasons. The ecological side of the problem is seen in ending numerous products at waste dumps and in depletion of non-renewable natural riches. The economical side of the problem of disassembly is seen in the need for a design of the disassembly system in a way that the value of the disassembly process result is grater then the resources invested for its proper functioning (Lazarevic, 2009). When designing disassembly system the designer has to consider end of life strategies and strategies selection for product.

3.1 Strategies for Products at the End of the Life Cycle

Users of products have two crucial difficult decisions to make: one is decision when to replace a product after its use and the other is what to do with the products when they decide to replace it. It is not unusual for some users to decide to sell the product and replace it while it is still in good condition. Therefore, the price of that kind of product is higher and the budget for buying a new, technologically advanced product is also higher. There are also some users which utilize their products until they became technologically outdated. After that, they leave them to the company responsible for end of life product processing. For many different reasons products arrive to the end of life product storage. Some of them may be discarded, but their vital elements can be in good condition, so they can be reused as spare parts in the maintenance process. All this leads to a conclusion that there is a need to determine strategies for the product at the end of life cycle.

Studies related with the strategies of the products end of a life cycle are numerous (Lazarevic, 2009; Mehl et al., 1994). The most accepted, and in its character, the most comprehensive classification of the products end of a life cycle is (Rose et al., 1999):
1.   re-use of used products,
2.   reconstruction of used products,
3.   usage of already used products for spare parts,
4.   recycling with disassembly,
5.   recycling without disassembly,
6.   dumping of the used products.

Re-use of already used products is a strategy that organizes the return of discarded products which are still in function. If such an interest exists, already used products are sold in the market.

Reconstruction of used products is applied due to modernize or to upgrade their performances. The purpose of this strategy is to attain a product, which is in quality less or very similar to the quality of the new products. The quality of the reconstructed products depends on the determined depth of disassembly. If a product is disassembled to the level of parts and a control and a replacement of all parts is conducted, the used products are brought to a high level of quality, required for the new products.

Also, it is possible to conduct the modernization of products, by replacing certain modules with contemporary ones, after applying the disassembly.

Appliance of already exploited products for spare parts is being frequently used. In certain companies, out of date products are being collected in an organized manner. The purpose of this strategy is to take a relatively small part of sub modules from a used product and use them for the above mentioned strategy, or for another purpose, and the rest will be used for material recycling.

Recycling with disassembly is a strategy used for separating parts made of different material, before its conversion in the process of disassembly. The purpose of this strategy is to use the materials from the used products and parts, by separating them in the procedure of disassembly into the element parts and with appropriate selection, depending on the

determined type of material. These materials can then be used in the production of original or some other products.

Recycling without disassembly is a procedure, which is used to compact and compress the product and then crush it and sort it by type of material.

Disposal is, from the ecological point of view, the most inconvenient strategy for disposing products on the waste dumps. Having the above mentioned strategies in mind, it is necessary to design an appropriate production system.

3.2 Strategy Selection for Product at the End of the Life Cycle

The system for product processing at the end of life cycle has a quite complex structure, since there is a need for more then one technologically different subsystem like (Lazarevic, 2009):

1.   disassembly,
2.   reassembly,
3.   recycling,
4.   waste incineration,
5.   hazardous waste storage,
6.   waste storage.

The choice of strategies for reconstruction of used products (2), usage of already used products for spare parts (3) and recycling with disassembly (4) are made according with the both momentary product condition and suggestions taken from the database for particular product. A system for product processing, according with chosen strategies for product management at the end of the life cycle, is shown in the next figure (Lazarevic, 2009).
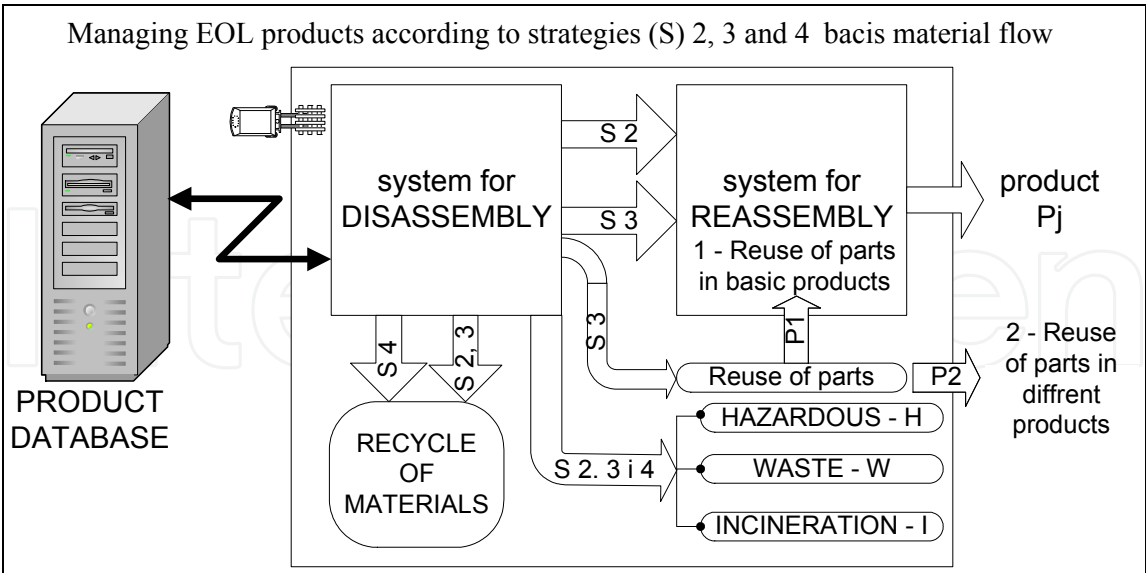

Fig. 5. System for processing the products at the end of the life cycle (Ostojic et al., 2008)

In the most general case, if for the given product (p_i), all three potential strategies are chosen as possible, which comprise the need for disassembly (strategies 2, 3 and 4), then the production system for processing of such products contains in itself all the elements as in
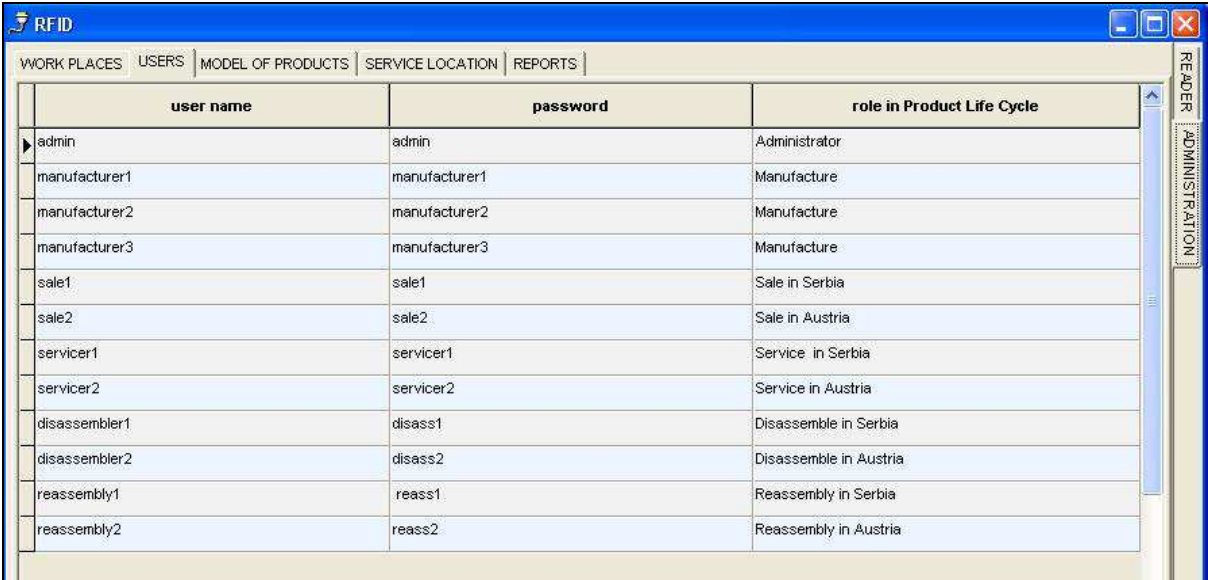
the previous figure. In case when only the strategy number 4 is chosen, then a subsystem for repair does not exist.

When choosing strategies 3 and 4, a subsystem for repair possibly exists. Depending on the type of product and the type of repair, the repair subsystem does not have to be specially separated. It is important to notice that in the procedure of the product disassembly, during the parts selection, a flow of materials must be planed for the parts that are headed for reassembly. In other words, it is often very possible to conduct, in a same place, within one subsystem where the disassembly is conducted, a second assembly of the product.

3.3 Model of RFID technology application in assembly/disassembly systems and other phases during the whole product life cycle

In order to ensure the adequate supervision and control in all the phases of the product life cycle (depending on the type of product and level of supervision and control), an appropriate automated system is designed. Hardware system elements depend of the function to be executed in specific phases of the product life cycle, but the basic component is only a PC with Intranet/Internet connection and any kind of Internet browser. This kind of system enables only supervision in some of the phases where this supervision function should be available. This basic system can be expanded by adding a RFID reader and its connection to PC (RS 232, USB, or TCP/IP), but only in some of the phases of the product life cycle, where the control function is needed. The software system components include web-based application software, and the software application depends directly on selected products end-of-life strategy defined in the product design phase.

As presented in Fig. 4. and 5., the automated system for product monitoring enables interactive communication between the database, user and product in every phase of the product life cycle. The system designed in this way enables authorized users (Fig. 6.) to get an insight into the momentary status of a particular product, since the status of the product is changing from phase to phase during the life cycle.

user name	password	role in Product Life Cycle
admin	admin	Administrator
manufacturer1	manufacturer1	Manufacture
manufacturer2	manufacturer2	Manufacture
manufacturer3	manufacturer3	Manufacture
sale1	sale1	Sale in Serbia
sale2	sale2	Sale in Austria
servicer1	servicer1	Service in Serbia
servicer2	servicer2	Service in Austria
disassembler1	disass1	Disassemble in Serbia
disassembler2	disass2	Disassemble in Austria
reassembly1	reass1	Reassembly in Serbia
reassembly2	reass2	Reassembly in Austria

Fig. 6. Authorized users of web-based application software

In some phases, during the product life cycle, it is necessary to change information about the product. This activity is done by authorized users responsible for writing this information, whether only to the database or both to the database and RFID tag placed on the product, thus enabling updating information about the current status of the product. Information placed in the database about a product includes:

- Product ID (UID read from the RFID tag assigned to a particular product).
- Product type.
- Date of issue.
- Date of first start.
- Recommended strategy for product.
- Recommended level of disassembly depending on the chosen strategy for the product.
- What elements can be used for spare parts?
- Services (dates and descriptions).
- Number of working cycles.
- Does it contain hazardous parts and materials?
- Does it contain already used parts or recycled materials? If so, which parts are those and what is the number of the remaining working cycles?
- Which part is the base part for assembly? etc.

Since assembly and disassembly phases of product life cycle are one of the most important special attention has been given to the structure of these systems. An example of RFID technology application is shown in Fig. 7 and Fig. 8. The proposed concept can be used for assembly and disassembly of product in order to increase flexibility and efficiency rate of the system in hand. Products can be assembled and disassembled on the same technological system according to the process plan and the product currently available at a particular working place.

An example of assembly is given in Fig. 7 and it follows the next routine: conveyer belt brings in the parts tagged with RFID. Upon arrival of the part at the first working place, the reader reads the RFID tag. The read out UID is compared to the UID from the data base, after which the data base issues a number of instructions for assembly presented graphically on-screen to the operator. The instructions are presented in a sequential manner, and are executed by taking the appropriate tool. Upon return of the tool to its previous position, next assembly instruction is initiated.

If a sequence requires no tool, then the next instruction must be initiated manually. Upon completion of the operation (all sequence of operation), the sequence of instruction for that particular working place is finished. The product is placed on the conveyor belt, travels along and, gets identified by RFID once again on another working place. If the product is to be machined at that particular working place, the signal light flashes and the operator takes the product off the conveyor belt. The process continues like in previous operation with a number of instructions coded for that working place and that product. In case all working places are currently busy, the product circles on the conveyor belt until a vacancy appears. The RFID tag is always placed on the base part.
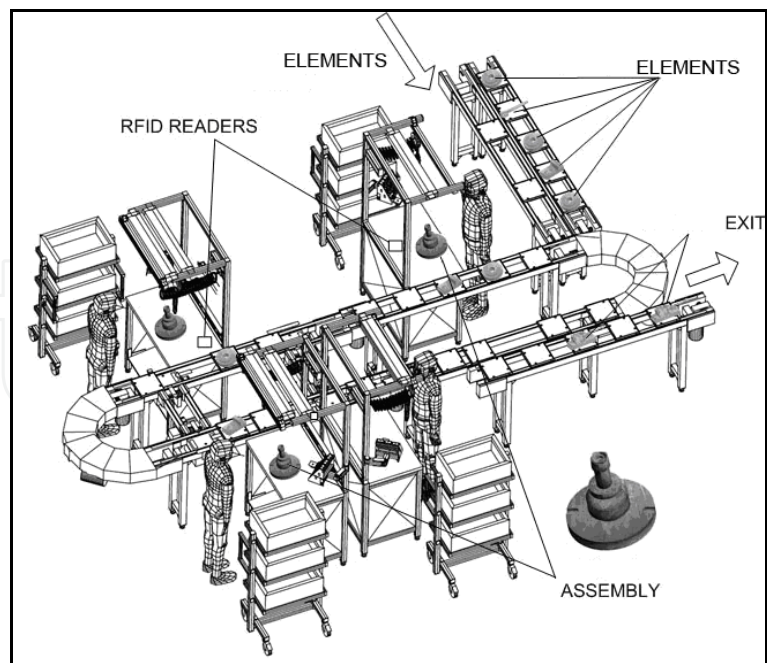
Fig. 7. Application of RFID in product assembly (Vukelic et al., 2010)

An example of disassembly is shown in Fig. 8 and it runs as follows: To the working place are coming products whose RFID tags are read out and one of the tag-stored strategies is adopted. The adopted strategy is written to the RFID tag and then the product is placed back onto the conveyor belt and forwarded to disassembly area. Beside the usage strategies, the RFID tag reader also reads the UID and adopts the appropriate sequence of disassembly operations, presenting them on-screen to the operator. The instructions are presented in a sequential manner, and executed by taking the appropriate tool. Upon return of the tool to its previous position, next disassembly instruction is initiated.
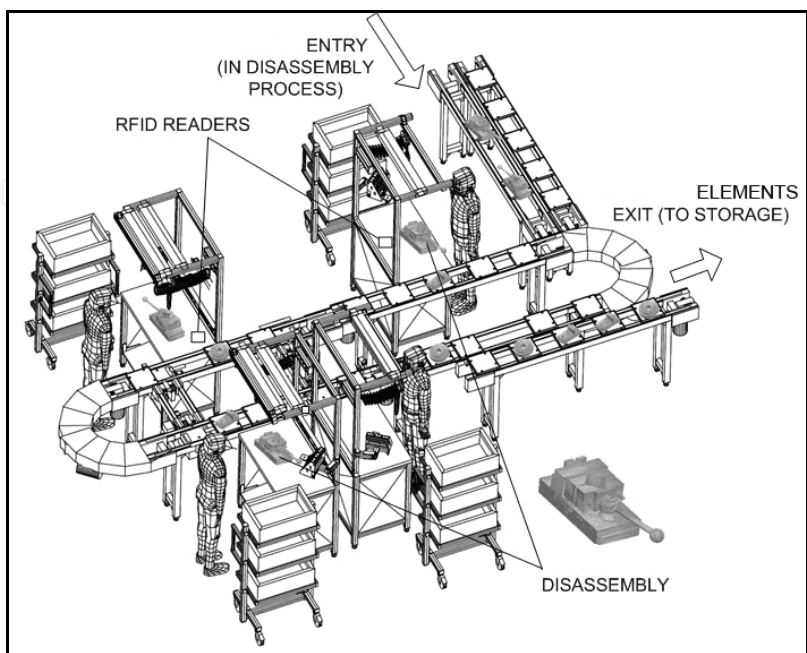

Fig. 8. Application of RFID in product disassembly (Vukelic et al., 2010)

If a sequence requires no tool, then the next instruction must be initiated manually. Upon completion of the operation, the sequence of instruction for that particular working place is finished. The product is placed on the conveyor belt, travels along and, gets identified by RFID once again on another working place. If the product is to be machined at that particular working place, the signal light flashes and the operator takes the product off the conveyor belt. The process continues like in previous operation with a number of instructions coded for that working place and that product. In case all working places are currently busy, the product circles on the conveyor belt until a vacancy appears.

If at some working place a product is disassembled which, according to selection strategies, can be re-used, then at that particular working place the element is labeled with a RFID tag, and the data on the element's previous usage are written in. Upon this, the element is transported to the place where (after the RFID tag data are read out) it is directed towards element warehouse for re-use, using the same conveyor belt for finished products, just as the assembly process, the only difference being that, instead of being directed to a machining process, the elements are directed appropriate containers.

The elements, for which a reconstruction strategy has been chosen, are transported on a palette to an appropriate container, which is then transported to the warehouse for product reconstruction.

Materials, which are to be recycled (secondary materials), are directed into containers for the secondary materials.

The system designed in this way can provide authorized users: data consistency, product condition overview, prediction of product status, real-time access to product information from every point of life cycle, product monitoring during the whole life cycle, etc.

4. Case study: Implementation of RFID technology for IML robot monitoring

In-mould Labeling (IML) is a technology where the molded plastic items are being labeled before they are formed (Bloss 2008; Hyland 2001). Using different kinds of robots or manipulators, labels are fetched into the mould of plastic injection molding machines (IMM). Any manufacturer that uses IMM requires machines capable of achieving shorter mold cycle time, meaning that the time requires shorter post-molding processes. The key point is to position labels into the mould quickly and accurately between each mould cycle and removal of parts, after the injection process has been finished. This applies to both the IML technology and post-molding processes. One of the recent trends in the IML technology is to use the same robot to insert the labels and to extract the finished parts, which involves elimination of subsequent processing steps a shortening the post-molding cycle time. In this way, subsequent processing steps are eliminated and the post-molding cycle time is shortened (Stankovski et al., 2010).

Following this approach, one of machines producer, Center for Automation and Mechatoronics (CAM), has developed IML robots (www.cam.rs), series RT-XX, which are fully pneumatic, and designed, for access to the molding area from above of IMM machines, as shown in Fig. 9.
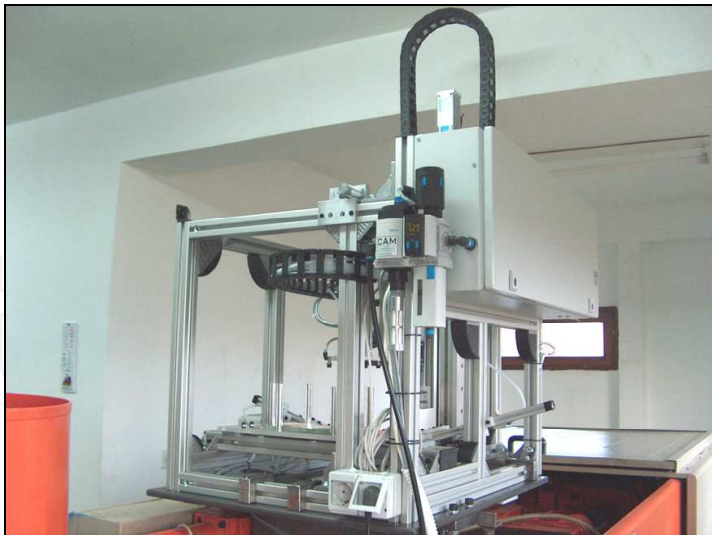
Fig. 9. CAM IML robot series RT-10

The basic idea in the case of CAM IML robots is to have the possibility to track down how many mould cycles are done and save the data on the RFID tag (see Fig. 11.). These data will be used in a proper way in the product life cycle, as explained above and shown in Fig. 4., to organize the processes of assembly and disassembly. If we look at Fig. 10., it can be seen that there are three axes that the manufacturer wants to monitor during the exploitation time. In one molding cycle, the axes have different amount of cylinder cycles. Also, the axes have different amount of cylinder cycles for the working period (min. 5.000 km) as shown in Table 1.

Axe	Working stroke	Amount of the cylinder cycle in one moulding cycle	Amount of cylinder cycles in the working period
A	1000 mm	1	> 5.000.000
B	400 mm	1	> 12.500.000
C	250 mm	2	> 20.000.000

Table 1. Data for three axes for one molding cycle and the working period
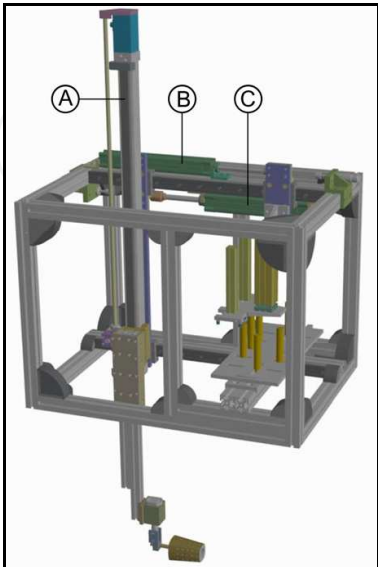

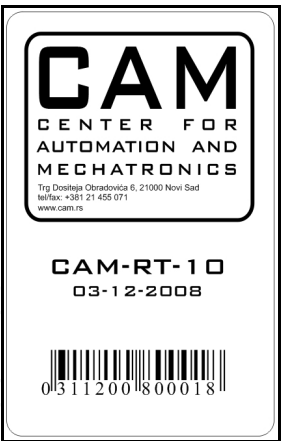Fig. 10. Three axes that have been monitored on IML robot

Fig. 11. The RFID tag for the IML robot

It is important to emphasize that almost all elements from the CAM IML robot can be reused after the disassembly process. Main elements and their characteristic, as well as recommended strategy at the end of their life cycle in the regular use are given in Table 2.

Element of IML robot	Working period	Strategy selection
Cylinder	> 5000 km	1, 2, 3, 4
Valve	> 2 500 000 cycles	1, 5
Sensor (without mechanical contact)	> 4 000 000 cycles	1, 5
Tubing	(Practically) Unlimited	1, 3, 5
Programmable logical controller (PLC)	(Practically) Unlimited	1, 3, 5
Aluminium profile	(Practically) Unlimited	1, 3, 5

Table 2. Main elements of the IML robot with their characteristics and possible strategies

As already said, all main elements used in the CAM IML robot are standard, and can be reused in any kind of process or implemented in a different product that requires these elements. Having this in mind, the data written on the RFID tag are as follows:
- Robot type (RT-XX)
- Date of issue
- Date of first start
- Recommended strategy for product (2, 3, 4)
- Date of services
- Amount of molding cycles
- Amount of cylinder x (A, B, C) cycles, etc.

All data on the RFID tag are encrypted. First four data are written only once. After completing the recording of these data, their memory is blocked, in order to stop any later change. Date of services is related to every date when the service on the robot is done, and this is also a memory-blocked data. Last four data have to be written after every finished working cycle. In order to accomplish these requests, the PLC has to be connected to an HF RFID reader. Operating frequency of the RFID reader is 13.5 MHz. The RFID reader is located in a plastic control box, fixed to robot's back side. On the opposite side of the control box is the RFID tag (see Fig. 11.). The PLC and RFID reader are connected using RS232 ports.

A communication protocol is defined by a manufacturer of the RFID reader. The communication protocol consists of commands for reading and writing data, and commands for changing parameters of the RFID reader. Every time, when the robot is turned on, the control program on PLC passes through a cycle shown in Fig. 12.
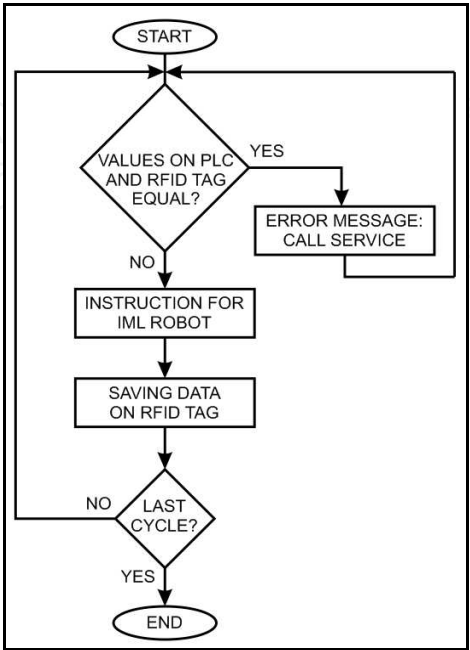

Fig. 12. The PLC cycle on the IML robot

This PLC cycle enables the RFID tag to keep reliable data. The case that an unauthorized person tries to change values written in the PLC registers or to replace the PLC, the program will stop the robot and further work can be enabled only by an authorized person. In that moment, the data which are written in memory space for the amount of cylinder cycles will be blocked. In this case the RFID tag is used as PROM (Programmable Read Only Memory) memory and it has following advantages:

- the RFID tag keeps reliable data,
- data on the RFID is not possible to change.

The main reason for using RFID technology this way is not only to get insight into the key information about the product but also to forecast the working period of the IML robot. In case for this particular robot the end of life cycle can be reached in almost two years after its first start, when the first requirements for replacement of the some crucial parts can be expected (related to strategy 2). This information is very important, not only to the IML robot manufacturer to be prepared for the processes of robot repair or disassembly, but also for the robot parts suppliers to be ready to fulfill the expected repair part requirements. As the final objective, the user will have the IML robot ready in a short time.

The amount of data, which can be written on RFID tag, is limited. This is a disadvantage of the RFID tag at this moment. But, if an authorized user wants to get insight into all available information about a particular robot (not only information written on the RFID tag), he/she has to access the database via web-based application software by entering unique identification of the robot and afterwards accessing expanded number of information like:

- Recommended levels of disassembly depending on the choice of the strategy for product.
- What elements can be used for spare parts?
- Services (dates and descriptions).
- Does it contain hazardous parts and materials?
- Does it contain already used parts or recycled materials? If so, which parts are those and what is the number of their working cycles remained?
- Which part is the base part for assembly? etc.

In this way the authorized user can determine two basic things. First: the consistency of data written in the database and the RFID tag. If there is no matching between some of the data, there is a possibility that someone has, on purpose, changed the data. In this case, only data from the RFID tag will be consider as valid, and the data from the data base have to be discarded. Second: by making adequate decision according to his/her role in the product life cycle. For example, if the user is a service worker, key information is: date of first start, date of the last service and what was done at that time, which part is the base part for assembly or what elements can be used for spare parts. According to accessed information the service worker can make decisions like: replace some parts (cylinders) if the working cycles are nearing or exceeding the prescribed working cycles - preventive maintenance, etc.

5. Conclusions

The use of RFID technology with the aim of monitoring product during their life cycle has proven to be very useful, especially in case when there is a need for products to be disassembled, since it enables quickly gathering necessary information about the structure and the composition of the materials in the product as well as possible strategies that can be used for parts of product that has come to end of life cycle.

Besides this, it must be emphasize the fact that the implementation of RFID technology has its limitations. First of all they can be seen in the problem of tag memory capacity. There is a limited number of data that can be written on the RFID tag. In case of complex products where they pass through many different phases of life cycle, there is a need for a large amount of information that can not be written only on the RFID tag but has to be written in the database. Another problem is the standardization of RFID tags, since there is a difference between the conditions in particular phases of the product life cycle. Also, the problem of standardization is related to different national regulations, since not every phase of the product life cycle has to be accomplished in one country.

In this chapter a model of RFID technology application in assembly/disassembly systems and other phases during the whole product life cycle is presented as well as writing and updating information about product. This method includes not only information about momentary state of the products, but also theirs basic elements, like cylinders in discussed case of IML robot. Writing information on the RFID tag and in database is done only by an authorized user. The proposed method enables redundancy for data storage and contributes the information reliability. The RFID tag keeps reliable data which are not possible to change and this is very helpful for the maintenance and disassembly process.

Future work should be directed to designing methods for identification of critical product elements, since their life cycle directly influence the product life cycle. Also, it would be of great importance to optimise the amount of data to be written on the RFID tag because of the limited RFID tag memory capacity.

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