IMPROVEMENT OF THERMOCHEMICAL FINISHING PROCESSES: AN APPLICATION OF A BATCH TRACING SYSTEM

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ABSTRACT
Manufacturing processes in the area of thermochemical treatment of work pieces impose lots of challenges due to the rough environment. High temperatures and the use of chemicals are aggravating conditions of salt bath nitrocarburizing processes, which are composed of preheating, nitrocarburizing, oxidizing, and multilevel cleaning. These stages are passed through consecutively, for what customer orders are combined in batches. At present, the implementation of batch tracing mechanisms is difficult or impossible due to the harsh environment. As a consequence, wrong assignments of the finished pieces to the customers may occur while a possibility of documentation of the parameters concerning the manufacturing process is desirable. In this paper, we discuss batch tracing by means of intelligent RFID technology (radio frequency identification), which involves connections to sensors for measurements of ambient parameters. This allows the company to offer new supplementary services to the customers and to design the process in a more flexible way like prioritizing time-critical orders. In order to prove the technical feasibility of batch tracing in the field of thermochemical treatment two test cases are described: The first one is for gathering information about the functioning of the installed RFID system, the other one is the realization of the operational process in a simplified form.

Keywords: batch tracing, RFID, harsh environment, production system design, manufacturing process

1. INTRODUCTION
The number of product recalls has been increasing over the past decade. Despite increasing quality, there is no certainty that only top-quality products which are free from errors reach the market. The latest example includes the 2010 Toyota automotive recall. Besides the loss of reputation, the administrative and logistical effort is very high for a recall. The issue of reducing product recalls and minimizes the potential economic damage in case of a recall has been sufficiently discussed in the relevant literature (Engelhardt-Nowitzki and Lackner 2006, Kletti 2006, Potter 2011). Therefore tracking and tracing of products and batches in production control and logistics will be increasingly relevant for industry, final consumer and, last but not least, legislator. Several of the following reasons for the enhanced deployment of batch tracing thus apply (Engelhardt-Nowitzki and Lackner 2006):

- Besides the fulfillment of functional performance of the product, the request of customers for security and information about the origin of ingredients and products is an important part (customer pull effect).
- The industry benefit form increasing in efficiency and advancing of process reliability (industry pull).
- Innovative communication, information and location technology, such as Radio Frequency Identification (RFID) which are combined with Global Positioning System (GPS) or Wireless Local Area Network (WLAN) are standard today and generate a technology push effect.
- New laws and regulations provide document information "one step forward and one step back" in the logistic chain (regulatory push effect).

Norms such as Code of Federal Regulation 21CFR820 (Quality System Regulation 2006) or European Regulation 178/2002 (Regulation No 178 2002) give little scope especially to the food and drug industry. This regulation is a comprehensive system of traceability and allows precisely product recalls. Safety-related mechanical components are subject to similarly stringent requirements. From the manufacturer's product liability for defective products arises across all branches of industry (Regulation No 84/374/EEC 1985). In order to restrict the extent of liability for the individual companies in the value chain, the identification of batches is mandatory. In addition to labeling products, packaging and packaging units will be identifying which ensure a seamless traceability.

In some industries (e. g. food, drug, steel, and thermochemical sectors), the batch production is discontinuous which is characterized by a material flow which is interrupted in time. In this context a batch is an amount of pieces which form a whole and are processed together and therefore exhibit identical attributes with regard to the manufacturing process and the product quality. Another feature of the batch production is limited capacity of the production system (e. g. thermochemical treatment processing system) and therefore only part of batches can be processed and removed afterwards. Due to the conditions of production the products produced in different batches vary and consequently variations in quality are obligatory (Engelhardt-Nowitzki and Lackner 2006, Günther and Tempelmeier 2000). For quality control purposes the operations of a detailed documentation of the production process are absolutely essential and are increasingly being leveraged in industry.

The ever-increasing demands of the internal material flow are the constant source within automated production control. In terms of material flow system has made great progress in recent years. The current trends are decentralized signal processing of sensors and actuators as well as reusable and exchangeable software components (Günthner and ten Hompel 2010). Intelligent infrastructure coordinates with transport units and allows to implementing a decentralized and variable batch tracing system. Particularly in combination with RFID, the design of the batch tracing system provides a way to satisfy the requirements for discontinuous production.

In this article we therefore propose the broad outlines of our research tasks, for the technical feasibility of an information system for the seamless traceability of work pieces through the stages of discontinuous production. The initial situation and the requirements of the problem are particularized for the real case of the integrants of thermochemical finishing processes. On the basis of the system requirements we discuss the feasibility check by the means of two test design patterns and describe the test results. We introduce the concept of network and system architecture for our batch tracing system. The paper ends with a disquisition of conclusions and outlook of the applicability of this system.

2. APPLICATION

We have attempted to apply the ideas characterized above to a real case from the industry. First the initial situation is described and the problem is presented.

2.1. Initial Situation and Presentation of the Problem

The company is a factory for the production of mechanical components including heat treatment. In the range of heat treatment the company deploys, among other things, the thermochemical treatment of the work pieces by salt bath nitrocarburizing by the TUFFTRIDE® process, which is used to improve the wear resistance, the fatigue strength, and the corrosion resistance of components made from steel, cast iron, and sintered iron materials. The use of chemicals and treatment temperatures of up to 630 °C pose a challenge to issues concerning this manufacturing process (Boßlet and Kreutz). The work pieces traverse various stages in a manually operated plant in sequence. Prior to that the formation of batches takes place by pooling customer orders. Thus the manufacturing process shows the characteristics of a discontinuous production.

At present, there exists a shortcoming in the process of the delivery of the work pieces, their thermochemical treatment, and their provision for supply to the customers: Although photographs on the order prints serve as assistance in recognizing, the refined pieces of a batch cannot be definitely related to the customers occasionally. The main problem is the missing identification of the charge carriers, which would allow an explicit assignment of the work pieces to the batches at the information level at the beginning of the process. Therefore there is a disruption in the information chain during the treatment of the pieces. As a consequence of the absence of batch tracing mechanisms there are wrong returns, which lead to customer dissatisfaction due to missed deadlines and additional transportation costs. Furthermore there exists no possibility of documentation of the parameters concerning the manufacturing process of the work pieces.

Through the implementation of batch tracing mechanisms the following objectives shall be accomplished in the medium term:

- In order to meet the increasing requirements of the customers, the company pursues the target of offering new services for quality management by documenting the manufacturing process of the work pieces. Essentially this is an automated analysis of the actual duration of the process and the temperatures in the individual stages of the salt bath nitrocarburizing plant for the work pieces. The compliance with regulations during the finishing process shall be attested by the help of greater transparency of the quality data. This important aspect of quality assurance shall reduce the product liability risk on the one hand and precisely determine possible causes of failure on the other hand.
- The identification and localization of the batches throughout the entire process shall help to design the process in a more flexible way like prioritizing time-critical orders.
- By assigning the refined pieces to the customers easily and more quickly and avoiding wrong returns with the aid of batch tracing, the non-productive time shall be reduced by 20 % and thereby the throughput shall be increased by 30 %.

The new supplemental services based on process documentation and prioritization of orders shall cause an enhancement of the market reach, by what a medium-term sales increase of more than 5 % is expected.

The idea is to realize the batch tracing system by means of intelligent RFID technology (radio frequency identification), which involves connections to sensors for measurements of ambient parameters of the process. For this purpose a feasibility study is conducted as a first step, in order to check the technical practicability of using an RFID system for the automatic identification of charge carriers, because in the field of implementation of RFID technology there is no standard solution, but rather the solution has to be adapted to the specific situation, particularly in this case due to the aggravating conditions of salt bath nitrocarburizing processes. However, the study does not comprise the issue of gaining and handling the temperature data. We now want to present the study und its results.

2.2. Process Analysis

The process analysis begins with the ascertainment of the current process of thermochemical treatment including the receipt of the work pieces and the allocation for their returning. Subsequently, we look into the question of how to apply RFID technology as part of the batch tracing mechanisms in the present case, prior to expanding the sequence of the finishing process by the handling of the transponder solution.

The work pieces delivered for refinement are electronically recorded and photographed in the receiving department and then forwarded to the department of thermochemical treatment together with the printed order copy. Here the consolidation of the customer orders to batches is carried out consecutively: The pieces are put into baskets, which are arranged in a pile forming the charge carriers. The number of baskets per charge carrier can vary depending on the size of the work pieces. After the cleaning in a washing plant, the next step is the thermochemical treatment of the work pieces by salt bath nitrocarburizing by the TUFFTRIDE® process, which is composed of preheating (PH), nitrocarburizing (Tufftride), oxidizing (AB1), and multilevel cleaning. These stages are passed through successively (see Fig. 1). Nitrocarburizing takes place in a salt bath at 480 to 630 °C, the standard temperature is usually 580 °C (Boßlet and Kreutz). The treatment is done in a manually operated plant: A hand-operated crane transfers the charge carrier from stage to stage. The crane can be positioned with an accuracy of about 10 cm. Several cranes run along a closed crane rail, hence the sequence of the cranes does not change.

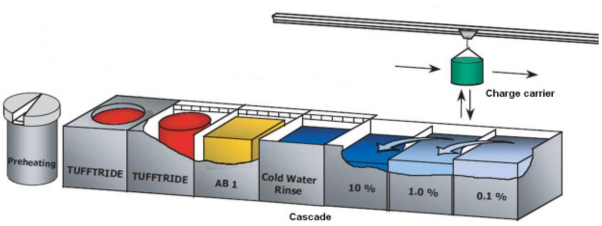

Figure 1: Tufftride®-Plant (Boßlet and Kreutz)

Two identical stages are available for nitrocarburizing however the batch carrier has to pass through only either stage. Since the stages are arranged one after another and the order of the cranes is invariant, it may occur that a charge carrier has to wait in front of the first nitrocarburizing stage, although the second one is vacant. In order to avoid such situations there is also the possibility of relocating from one to the other nitrocarburizing stage, because the procedure of nitrocarburizing can be interrupted.

After the thermochemical treatment lasting three to four hours, the process can be continued in three different ways:

- Ending of the process: The work pieces are provided for delivery to the customers. The assignment of the refined pieces to the customers is effected visually at what the photographs on the order prints serve as assistance in recognizing.
- Sandblasting and afterwards ending of the process.
- Sandblasting followed by assignment to a new batch and repeated thermochemical treatment.

Batch tracing shall enable the identification of the work pieces on the one hand and the possibility of documenting the duration of the treatment and the temperature in the different stages of the salt bath nitrocarburizing plant for the work pieces on the other hand. The identification of the work pieces is effected by the assignment to a batch, which is associated to a charge carrier afterwards. RFID technology is deployed for the automatic identification of the charge carriers. However, affixing the transponder directly on the charge carrier is not realizable due to the harsh conditions during the thermochemical treatment – but neither necessary, as the charge carrier can be unambiguously assigned to the crane, which is used for the transportation of the charge carrier. The crane is now equipped with a transponder. The fastening location of the transponder at the crane is situated up close to the crane rail and hence several meters away from the immediate environment of the thermochemical events. As a result, the requirements for the RFID system, especially for the transponders, reduce to an acceptable level. So the transponders are not attached to work pieces, packaging units, pallets, or charge carriers as is usual but to the means of transportation of the charge carriers. For every stage to be documented a reader is mounted on the crane rail. They are connected to a computer via Ethernet. The readers can be regarded as nodes of a network yet to be established where other parts are for example the sensors for measuring the parameters of the manufacturing process like temperatures or components which combine the RFID data, temperatures, and other data and edit them for further use.

In concrete terms, the handling of the RFID solution is integrated into the process of thermochemical treatment in the following way: The work pieces and the customer orders, respectively, are aggregated in batches and assigned to a charge carrier, which is marked by a metal label with a unique number. When the charge carrier is hitched to the crane after the cleaning, the mating of them takes place by reading the ID of the transponder of the crane, manually entering the number of the charge carrier into a PC, and relating both IDs. The readers in the different stages record the transponder as long as it is located there. Thus the duration of stay of a crane in a stage is logged by use of RFID technology and one obtains the desired data for the particular orders such as the beginning and the length of stay via the assignments crane – charge carrier and charge carrier – order.

2.3. Technical Feasibility Check

In order to check the technical feasibility of the transponder solution, requirements on the RFID system are specified and appropriate components are chosen followed by the definition of the test cases and the analysis of the data gathered by the tests.

The requirements on the RFID system arisen from the process analysis are a reading range of 10 to 20 cm, passive energy supply of the transponders, that is transponders without a battery, and fixed read/write devices. Bulk reading is not necessary. As the RFID system has to run in an industrial environment, it should feature a high degree of robustness. Based on these specifications an HF system is selected meaning that the RFID system operates in the high frequency range (13.56 MHz). The components of the RFID system should conform to the norm ISO 15693 which comprises a standardization of RFID technology in the HF range. According to the determined requirements the RFID equipment is selected for the desired application of batch tracing in the salt bath nitrocarburizing plant and is used during the tests: discoid transponders of 8.5 cm in diameter, readers with integrated antenna, and communication modules coming with an Ethernet connection to link readers to a computer.

In order to examine the RFID system under conditions close to reality, the tests are performed at the company on site. Transponders are attached to two of the eight cranes used for the transport of the charge carriers with the work pieces to be refined during the thermochemical treatment. The two cranes succeed one another directly. During the experiment two stages shall be monitored and documented: The first one is the stage “Start”, where the charge carrier is hitched to the crane and the mating of both of them takes place, and the other one is “PH”, the stage for preheating. A software application has been developed for this feasibility study. With the aid of this prototype the data and the RFID components can be managed. This includes among other things the establishment of a connection to the read/write devices, the receiving of messages concerning transponder events like the entering and leaving of the antenna field, and the assignment of a charge carrier identification number to a transponder just being read.

Two test cases are defined for the experiment:

- *Scenario A:* This test case is for gathering information so as to check whether the installed RFID system operates without technical problems or whether the rough environment has negative effects on the individual components of the RFID system. For this purpose it is continually recorded when the transponders enter or leave the antenna fields. The capture of these transponder events happens automatically without manual inputs being necessary, because the assignment of the batches is not taken into consideration in this scenario.
- *Scenario B:* This test case is the realization of the operational process in a simplified form. After the charge carrier is hitched to the crane for the treatment in the plant, their mating takes place in the stage “Start” by entering the unique charge carrier number and a description of the batch into the software application and assigning them to the transponder of the crane. By recording the entering and leaving of the antenna fields one gains the requested data about arrival time and length of treatment of the work pieces by batch tracing mechanisms exemplarily for the preheating stage.

For the reason that the data are available for the analysis, a text file is generated for each of the two test cases, where the recorded transponder events are registered. As opposed to *scenario A*, in test case B the transponder events are only logged if the transponder ID is related to a charge carrier ID for the respective passage through the thermochemical treatment. One data set is essentially composed of the name of the stage (“Start”, “PH”), the name of the transponder (“Ida”, “Ada”), the date and time of the entry and the exit respectively, the length of stay of the transponder in the antenna field, and additionally in *scenario B* the charge carrier number and the short description of the batch. Besides, data are manually recorded in case B, so that it is possible to check the RFID data against them.

After having installed the RFID system, it has been running for 20 days and collecting data continuously. The analysis of the data concerning *scenario A* yields a positive result in this test case. This means that the components of the RFID system, particularly the transponders and readers, operate satisfactorily and that negative effects cannot be detected which may be caused by harsh ambient conditions like high temperatures and the use of chemicals or by other potential interfering influences such as the metal parts of the crane or the crane rail where the transponders and read/write devices are mounted. The data of *scenario A* do not show a breakdown of a transponder or a reader meaning that it does not occur that a transponder is not read anymore or a reader does not record transponders anymore from a certain point in time. A data set, which is missing in the consistent succession of the data, along with a message about a thrown exception give an indication that, however, an interruption of the computer operation has happened at least once (see also *scenario B* below). Next we address the question of how many times a transponder enters and leaves the antenna field of a stage before the following transponder is read in this stage. Reasons for repeated entering and leaving are for example the positioning of the crane in order that the charge carrier is located exactly above the container for the treatment, into which the batch is lowered, or that the transponder is situated on the margin of the antenna field and enters and leaves it unintentionally. The transponder sojourns in the antenna field only once in a little more than half of cases and twice in approximately a quarter of cases. It is recorded three, four, …, or seven times in some cases and once even twenty times. The reading time is defined as the duration between the arrival of the transponder at and its departure from the antenna field. The acquired reading times of the events exhibit a few outliers: three in the stage “Start” and two in the preheating stage with values between 9 and 21 h. The explanation for these long terms is to be found in the circumstance that sometimes the batches are already positioned for later treatments in the stage “Start” or “PH” the previous day and thereby stay overnight or even, for example, from Sunday morning until Monday morning. The arithmetic mean of the reading times, calculated without the outliers, is 4 min for the remaining 167 events of the stage “Start” and 25 min for the remaining 118 events of the preheating stage. The reading times gathered in “Start” are distributed in the following way: 2 % of the events have values greater than 70 min (outliers), 10 % between 5 and 70 min, 28 % between 0.5 and 5 min, and 60 % less than 0.5 min. The duration of 46 % of the events is less than 3 s in fact (see Fig. 2). The reading times of the preheating stage show accumulations of the values in the ranges between 80 and 100 min (15 %), between 10 and 50 min (33 %), and less than 0.5 min (42 %). One third of the events last less than 3 s actually (see Fig. 3). The analysis of the reading times will serve as a basis for the determination of minimum reading times for each stage, which have to be reached in order that the event is registered, enabling to filter out the undesired events caused by positioning of the crane for example.

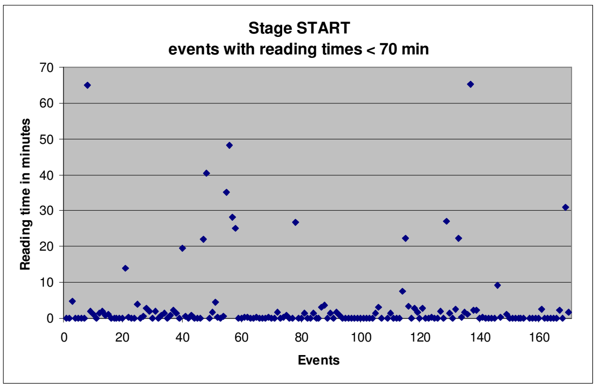

Figure 2: Reading Times for “Start”

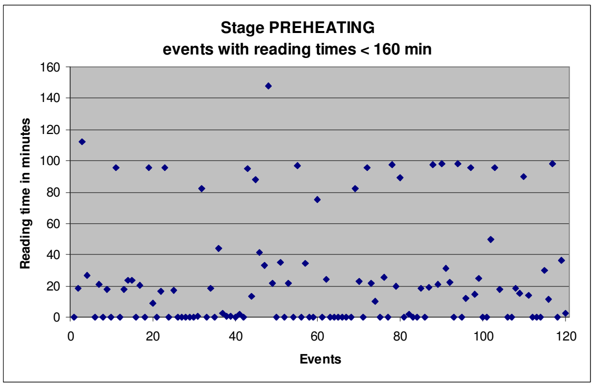

Figure 3: Reading Times for “PH”

In *scenario B*, the integration of the handling of the RFID system into the existing operational process, more precisely the entry of the charge carrier number together with a batch description into the computer and their assignment to a transponder, has been adopted by the employees of the company better than expected. The comparison of the manually recorded and the RFID data reveals that data sets are missing. The stay of the second transponder in the stage “PH” is not registered once and, at some other time, the data of the first transponder in the preheating stage and the ones of the second transponder in both of the monitored stages are lacking. In other words, the ending parts of two passages through the plant are not captured. However, the transponder events of the passages following the incidents are logged without any trouble-shooting being necessary or further problems then. This in combination with error messages of the software application implies that interruptions of the computer operation have occurred. For the analysis regarding the time data the manually recorded arrival times of the charge carriers are collated with the corresponding RFID data. The departure times are compared in an analogous manner. The greater of these two absolute differences is determined for each data set and is denoted by “D” hereafter. Only the data sets of the relevant preheating stage are taken into account and whose manually recorded data are complete additionally. The maximum value for “D” of the 40 data sets is 2.1 h. One quarter of the considered data has differences of less than one minute, another 30 % of the data between one and four minutes, and for the remaining 45 % the value “D” is greater than four minutes. The last-mentioned 18 data sets comprise two cases, where the manually recorded and the RFID length of stay are approximately the same but do not take place at one time, eleven situations the other way round, and five cases, where neither the lengths of stay nor the beginning or ending of the reading times of the manually collected and RFID data coincide. Several reasons for the deviations between the manually recorded and the RFID data are conceivable:

- The length of treatment of a batch manually logged does not equate to the duration of stay of the crane in the stage recorded by the RFID system, because the charge carrier is just waiting in the stage and is not lowered into the container for the treatment. In order to acquire the precise instant of time when the batch plunges into and emerges from the container for treatment, supplementary sensor technology would be required. However this is not necessary according to the company, since the charge carrier is not situated in a relevant stage like the one for nitrocarburizing without being treated, but is transported to the next step of the thermochemical treatment immediately.

- The transponder is not read all the time although it is located in the antenna field. (In the cases, where the lengths of stay differ, the RFID reading time is longer than the manually recorded one eleven out of sixteen times and therefore this reason could come into effect only for the remaining five events.)
- Errors when logging the data manually, as this takes places during the daily business.
- Minimal differences can be caused by the fact that the manually gathered data are specified in minutes whereas the RFID data in seconds.

3. GENERAL DESIGN PRINCIPLES

The following chapter provides a general overview of the network concept and system architecture for our batch tracing approach.

3.1. Concept of the Network

Based on the proven technical feasibility of the RFID solution, the subsequent main issue of implementing a batch tracing system is the establishment of the network, which comprises not only RFID devices like transponders and readers but also sensors for measuring the ambient parameters of the manufacturing process (e.g. temperatures) as well as components which combine the RFID data, temperatures, and other data and edit them for further use. Other elements of the network manage all these parts. In order to link the nodes of the network, an appropriate communication medium is necessary. A usual standard for this in an industrial environment is the connection of sensors, actuators, and control devices by means of buses. With increasing frequency, Ethernet is used beside traditional bus systems like Profibus, although it is not real-time capable (Gevatter and Grünhaupt 2006). However, response times in the range of milliseconds are sufficient in many applications – as for instance in the present one. Hence we have already deployed Ethernet for the connections between the read/write devices and a computer in the feasibility study. The use of Ethernet technology in an industrial environment for automation and process control is termed by "Industrial Ethernet". It includes the definition of cables, connectors, and the topology of the bus system (Schnell and Wiedemann 2006).

3.2. System architecture

The kernel of our batch tracing system is based on an existing generic application platform. The latter will be implemented adhering to the principles of service-oriented architecture (SOA) (Gioldasis et al.2003, 12f). The application platform provides base classes with generic services, which can be used to implement domain-specific batch tracing environments.

Service orientation models the manufacturing process into physical (e.g. readers or sensors) and virtual devices (e.g. stages or charge carriers). A physical device is specified by services which describe process-relevant information and is represented as atomic module and cannot be further broken down. A virtual device is a set of application functions for the manufacturing process. Physical devices are related to virtual devices and provide status information about the material flow. In this way the manufacturing process based on the "Industrial Ethernet" can offer his functionalities through services. The main intention has been to enable domain experts (i.e. shift manager or supply chain manager) for using batch information without the need for detailed manufacturing process expertise.

One of the next steps in the course of the implementation of batch tracing mechanisms will be the elaboration of this concept of the network and system architecture in more detail.

4. CONCLUSIONS AND OUTLOOK

Summarizing the results of the technical feasibility check, there are not detected any criteria against the application of RFID technology for the intended identification of charge carriers or rather of their means of transportation in harsh surroundings of thermochemical manufacturing processes. Though the question of the impact of incrustations, which are caused by the thermochemical processes and which are formed over time, has not been cleared up in the course of the three-week testing phase, the contaminations should not become a problem, since the selected components of the RFID system feature a high degree of robustness and are designed for the employment in industrial environments.

The technical feasibility proved by the conducted study serves as basis for the further implementation of batch tracing mechanisms in a salt bath nitrocarburizing plant. The next step for this purpose is the establishing of the RFID system for all stages to be monitored and all cranes and also the elaboration of an appropriate overall concept. An item to be approached for the draft is the definition of use cases in detail. The issue of the mating of the charge carrier and the crane, which enables the identification of the batches throughout the entire process, is necessary as a prerequisite. Besides the resultant possibility of documenting the beginning and length of stay of the treatment for the work pieces, another use case is the deposit of schedules for the treatment times of a batch in order that flares or audio signals can indicate when the treatment of the batch is finished in one stage and the charge carrier can be transferred to the following stage. Additionally the overall concept includes the design of the information flow that is the interfaces to other systems, the software architecture of the control system, and the hardware topology. Apart from the implementation of an RFID system, a further objective to be accomplished is the gathering of ambient parameters of the process, like temperatures, measured by sensors of the plant and their linkage to RFID data in order to realize a batch tracing system for thermochemical finishing processes by means of intelligent RFID technology.

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