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Consistent ladle tracking for optimisation of steel plant logistics and product quality

TrackOpt

Public

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Project summary

The project will implement automated ladle tracking systems to ensure consistent factory-wide tracking of the product from steelmaking via casting to delivery. The wireless tracking system in harsh steelworks environment will provide mandatory input data for projects on digitalisation (“Industry 4.0”). Automated, reliable information on actual position of ladles result in increased factory output (avoided hold-ups or downgrading of products due to mix-up of ladles) and in improved safety in steelworks. Furthermore the ladle tracking system will be used to optimise ladle logistics during both smooth production conditions and in case of sudden disturbances in production plan.

1. State of the art

The digitalisation of industrial production has become of large interest since around 2011. Especially in Germany many studies and reports (like [1, 2]) have been published and discussed very intensively. Here also the term "Industrie 4.0" has been born to describe, that a new generation of industrial production is coming up, if a consequent digitalisation will be realised. In other countries different names like "Smart Factories" or "Usinor future" are used, but the idea behind is completely the same. All these terms are originated by the manufacturing industry in which it is much easier to follow the product along the production chain, which is a precondition to realise so called "Cyber Physical Systems". In [3] and [4] the perspective for steel industry regarding the topic of digitalisation is discussed and here the point of "product tracking" has been mentioned as one the most important points to realise a "smart factory" in steel industry.

Since logistics in the steel plant was found to be a key factor for steel production with high quality demands, several approaches for improved steel plant logistics can be found in literature. Besides logistic models for material requirements and crane movement in the steel plants, the optimised transportation of the liquid steel in ladles through the different treatment stations in the steelmaking process has been a focus of research [4]. The approaches differ in their purposes: some concentrate on improving temperature control of ladle and steel [5, P6], others are focused on overall plant optimisation [6, P1].

A common way to reproduce the actual logistic conditions of a steel plant is computer simulation of the steelmaking process [8-11, P2]. Simulation is a useful tool to analyse logistic problems, bottlenecks and potentials in steel production. All the simulation results to improve ladle logistics in the steel plant are more or less based on the assumption that all devices of a steel plant are available at specific times and locations. If disturbances occur in the steelmaking process, the chances of carrying out the optimised offline logistics concepts are small, and alternative process routes have to be found.

Modern manufacturing execution systems (MES) offer more flexibility for optimum ladle logistics in steel plants [12, 13]. By collecting huge amounts of available process and production data, MES systems combine up-to-date information from the overall plant and the steelmaking process and react on disturbances with updated production planning.

One important indicator for the actual status of steel production is the current positioning of the ladles in the steel plant. In order to support the process control system with current process information, ladles are checked in and checked out manually by the operators upon arrival and departure at the different treatment stations in the steel plant. This procedure does not ensure consistency of the data due to the fact that there is no automated identification of the ladle at the treatment station and no automated connection and interaction with the production planning system. In the downstream area of steelmaking, attempts have been made to automatically identify slabs and ingots using bar codes and warm embossed stamping [22]. However, these visual techniques for identification purposes were found to be not feasible on steelmaking ladles, probably due to the harsh environment (dust and high temperatures) in steel plants.

A much more promising technique is radio-frequency identification (RFID) that has been used for the last three decades to identify objects, people and animals. An RFID system consists of a transponder (RFID tag with a passive antenna) attached to the moving object that has to be identified, and of an interrogation unit (RF antenna and reader) receiving the signals from the transponder. A distinctive feature of RFID tags is their frequency range: Low frequency (119-148.5 kHz), high frequency (13.56 MHz), ultra high frequency (865-955 MHz) and microwaves (2.4-2.4835 GHz) [14]. The major drawback of standard RFID tags intended for use on steelmaking ladles with surface temperatures at the steel shell of up to 400 °C is that they are mainly made of semiconductors, with maximum operating temperatures of 85 °C (125 °C military specification). Special multilayer insulation methods were needed to allow their application on transport ladles for liquid aluminium with ladle shell temperatures of 130 °C [15, 16].

Consistent tracking of the product throughout the whole steel production process, from tapping of liquid steel to delivery to customer, has not been addressed by ECSC/RFCS research in the past, neither automated tracking of steelmaking ladles. The proposed approach in this project regarding ladle tracking is to use high-temperature resistant passive surface acoustic wave (SAW) tags fixed to the ladles. These tags can be queried with automatic reader units at the different treatment stations in the factory to uniquely identify the ladle. This gives a safe method of entering the ladle ID into the process control system. Therefore the risk of ladle mix-up that can lead to accidents, hold-ups or downgrading of a steel melt can be drastically reduced.
In RFCS Project P1, a factory-wide production monitoring system was studied and successfully applied for different tasks and on different levels. Project P1 proved that monitoring systems increase work efficiency, allow checking of the status of operative practices during the process or reporting to the interested user upon the occurrence of predefined events. In RFCS Project P2, schedulers were used to optimise different parts of the steel supply chain and production simulation was used to validate the plan. Project P6 worked on through-process optimisation for the liquid steelmaking route with centre of attention on control of steel temperature under consideration of the thermal ladle status. Also here the ladles in the steel plant were tracked manually to acquire the relevant data for characterisation of the ladle status [23]. Project P7 focused on quality parameters and plant throughput in steel processing plants and applies Multi-Objective Optimization (MOO) techniques based on Genetic Algorithms for the identification of the best process route [28]. Project P8 developed a completely new paradigm for steel specific, factory- and company-wide automation and information techniques, replacing the usually centralized planning by a decentralized planning and optimization. The new paradigm of project I2MSteel [P8] would benefit from a suitable tracking of ladles in the steel shop, but the objectives of TrackOpt were not touched by I2MSteel. Out of this reason the project TrackOpt would be an excellent addition/complement to I2MSteel. Projects P9 and P10 are further examples of application of MOO techniques in the context of steelworks and of handling problems which are relevant from the environmental point of view. They have proven the application of Multi-Objective Optimization (MOO) techniques in real-world applications and the knowledge will be used within the project TrackOpt for **new applications** regarding ladle logistics in the steel plant.

The pilot and demonstration project will use monitoring systems together with production schedulers transferred to steel making ladles. It will introduce **automated monitoring** by means of tracking ladles with tags attached to the outer ladle shell, read by antennas and readers. The project will benefit from the experiences gained in previous projects, especially [P3, P8, P10]. It will **go one step beyond** and use the information from the automated ladle tracking to analyse ladle motion patterns, to identify possible bottlenecks during transport in the steel plant, and to propose strategies for improved ladle handling and short-time scheduling.
To implement the tracking system SAW tags are attached to the steel working ladles that are read out by RF antennas. Different to RFID tags built on the basis of semiconductors (with maximum operation temperature of 125 °C), SAW tags are made of ceramic material without any semiconductor. Thus they can withstand much higher temperatures (up to 400°C) for a prolonged time period. In Project P5 SAW tags were tested in laboratory at temperatures up to 800 °C. In RFCS Project P3, the same SAW technique as in the project TrackOpt is used for innovative refractory temperature measurement. This helps to monitor the thermal state of steelmaking ladles and will be used to improve the steel temperature models of the steel plants. Additionally this information assessment can later be combined with the ladle tracking system that will be focus of the project.
Also the work found in literature shows the SAW tags to be tolerant to elevated temperatures [17-20]. It was specifically shown that SAW tags can be attached to steel ladles and do not degenerate for several months [19]. In addition, the SAW tag can operate passive (without power supply) in the 2.4 GHz frequency range and the operation range is higher than IC-based passive RFID tags in the frequency range near by 900 MHz [21]. The pilot and demonstration project will start at this point and use SAW tags and RF antennas as hardware for

ladle tracking. It will then go beyond the testing of equipment described in literature and will apply an SAW setup for permanent tracking of ladle movements to use the acquired data for optimisation of ladle logistics and production scheduling.

EU project P4 focuses on safety of personnel in mines and in emergencies. The project aimed at monitoring the position of personnel to identify when someone enters a dangerous area. In contrast, this pilot and demonstration project aims to monitor the position of steel ladles, and to identify areas in the steel plant that are possibly dangerous to be passed by personnel.

With regard to ladle logistics, literature can be found on models for improved ladle logistics and computer simulation reproducing the steelmaking process, as well as on modern manufacturing execution systems that incorporate both process control models and simulation calculations [6-13, 23]. All these approaches suffer from the problem that they have to rely on manual acquisition about the actual ladle position and the connected ladle data. In the pilot and demonstration project TrackOpt the feedback about ladle position will be read out automatically at specific stations. Therefore, the project will be able to rely on more **exact and consistent data** for ladle positions to improve ladle logistics.

On the logistic side, the precise knowledge of the ladle positions in the steel plant will also enable to better react to malfunctions. Different techniques can be applied: constrained based local search (CBLS [24]) can be used to explore alternative solutions close to the initial planning and minimising the impact of some deviation, e.g. unforeseen events as delays, plant equipment failures. The presence of uncertainty in the future can be accounted for using specific OSCO algorithms (online stochastic optimisation problems), either based on Regret/Consensus algorithms which rely on optimisation techniques for value estimation [25] or Monte-Carlo Tree search (MTS) [26] which rely on discrete event simulation (DES). Multi-Objective Optimisation techniques (MOO) also based on artificial intelligence (AI) can be used in order to find a suitable trade-off among different counteracting objectives related to the process by taking into account complex constraints, according to an approach which has already found successful application in the logistic field, such as in the exemplary case depicted in [29]. The data gathered from the ladle position will enable to infer the required probabilities to enable such kind of optimisation with respect to transportation times, treatment times, melt residence times, and best fitting thermal and metallurgical condition of the steel ladle. This will result in a **better operation** of the factory where deviations are either avoided or recovered in a cost effective way. Additionally the new information about actual ladle positions will support the production scheduling by predicting arrival time of the ladle at subsequent treatment stations.
Finally big data and data mining tools (as in [36, 37]) will be applied to allow the continuous improvement of the tracking system and the logistics by exploiting machine learning tools. In particular, the application of reinforcement learning algorithms (e.g. Q-learning) is envisaged [30], but evolutionary algorithms will also be evaluated.

2. Problem description

"Smart factories“, "Industry 4.0“ [1, 2] and "Integrated Intelligent manufacturing (I2M)“ [3, 4] are at the moment buzzwords which are describing one current trend in nearly all industrial areas in Europe: the trend of digitalisation and integration of complex industrial production chains. The ideas and concepts to realise for example an "Industry 4.0“ environment in steel industry are just under development, but one is very clear just now: Important parts of "Industry 4.0“ in steel industry will only become reality if solutions to track all intermediate and final products along the complete chain of steel production and beyond that up to the final customer will be available. The reason therefore is that in "Industry 4.0" and comparable initiatives data acquisition and data storage has to be related to a clearly identified piece of “product” and not e.g. time oriented. Because of the large complexity of steel production and the number of different "products“ (hot metal, steel melt, billet/slab, coil/bar/rod/wire, etc.) passing through an industrial production site, this **tracking is a real challenge** and definitely not solved in several areas of steel production. Especially in the steel plant, many lacks regarding tracking exist: In the steelworks, tracking of the ladles transporting the liquid steel from steelmaking through secondary metallurgy to casting is usually done manually and thus error-prone. **A mix-up of ladles is a safety hazard and a quality issue** due to casting the wrong quality or because remaining steel in the ladle does not match the composition of the next heat. Robust and cheap solutions for this task are still missing.

Despite the crucial role that ladles play in modern steelmaking logistics, with production stoppages or substantial final steel quality issues in the case of delayed or wrongly delivered liquid steel to the casting process, the process control systems **have to rely on manual feedback** about the actual position of the ladles. It is still common practice for the operators to manually type in the number of the ladle at the moment it arrives at a treatment station. If at this moment the operator is occupied with other tasks, the time logged into the process control system becomes inaccurate. In addition, it can happen that a wrong ladle number is accidently typed in, possibly leading to a ladle mix-up. Therefore, this procedure greatly affects the accuracy of the production planning and process control systems and limits their possibilities to improve ladle logistics based on actual data. Ladle mix-up can lead to wrong treatment, with the **risk of impairing product quality, damage of facilities or even fatal accidents**. For example, the tapping into a wet ladle occurred, which led to the expel of 4700 kg slag, 23000 kg liquid steel and 1400 kg refractory material and caused the death of five workmen [5].

Due to missing automated ladle tracking, the product delivered to the customer often cannot be related to a certain ladle. In consequence, errors detected in quality checks cannot be related to the exact heat, and thus an analysis for the reasons of final product deficiencies to time or length related process information is not possible.

In Europe, most steel plants have a long tradition and are therefore subject to constant changes: new treatment stations are installed, old ones replaced, often space is restricted, sometimes new factory workshops are build. Ladle logistics are then adapted, but with the focus on production feasibility rather than on optimised motion in terms of transportation time and safety.
A typical example is the electric steelmaking plant of Ferriere Nord, where the project is performed. The plant was built in 1974 and then continuously developed during following years, starting with the implementation of a 70-ton AC electric arc furnace up to now to the 148-ton AC installed in 2013. The ladle furnace was put into operation in 1990’s and renewed in 2015. The ladle fleet consists of 10 ladles, of which 5 are in use at the same time, transporting liquid steel from EAF to LF treatment station and after secondary metallurgy treatment to continuous casting. Continuous casting machine was revamped in 2015. Casting sequence lasts for 40 heats. Tap to tap time and casting sequence are 47 minutes. After solidification the billets are transported directly to rolling furnaces or to stocking area before rolling. Two rolling mills transform billets in bars or wire rod. Ferriere Nord therefore is a well suitable industrial partner for this **pilot and demonstration project**, as it aims to focus on an **automated ladle tracking system** that will be a fundamental device **on the way to complete product tracking**.

Besides the difference in ladle motion due to different treatment and casting options, another logistic aspect is of importance in steel plants: Which ladle is the best to use for the next tapping sequence at either electric arc furnace or basic oxygen converter? Three aspects play a role in that decision:

- Is the thermal state of the ladle adequate for the next heat?
- Is the ladle fitting from metallurgical point of view, as small amounts of steel and slag are left over from the last heat? and

- Considering repair, preheating and transportation times, how long does it take until the most suitable ladle can be transferred to the tapping position, and does this fit to the production schedule?

Automated ladle tracking can support the decision by providing exact data about residence times at the different stations (heating, treatment, casting), as well as idle and transportation times.
Ladle logistic and its optimisation have not been a concern of many steel plants in the past, mainly because automated tracking and therefore reliable data provision was lacking.

Based on the experience made with an automated ladle tracking system, together with a realised tracking of intermediate and final products, many different applications in the fields of plant-wide monitoring, product quality control and/or production planning can be envisaged. **Their impact lies in the fields of cost reduction, quality improvement, increased yield and energy reduction.** Out of the above reasons the tracking of ladles along the production chain plays an important role for the future of steel production in Europe.

3. <u>Proposed approach</u>

The pilot and demonstration project will focus on solutions for consistent tracking of steelmaking ladles throughout the whole steel plant (**Figure 1**). These are mandatory to achieve a complete traceability of product quality together with logistics and control software.

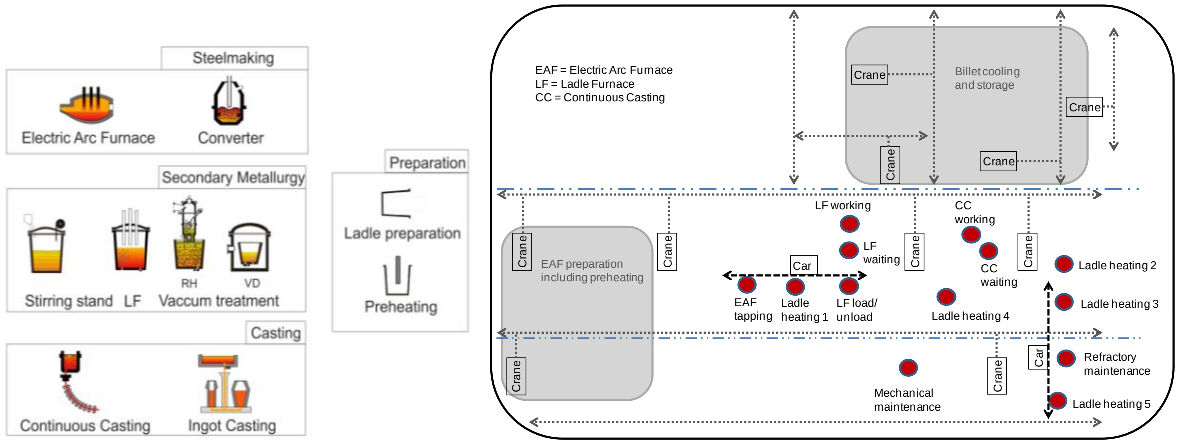

Figure 1: Overview of possible production steps and aggregates within a steel plant (for electric and oxygen steelmaking) (left) and exemplary plant layout with crane and ladle car tracks (right)

In the project, a **ladle tracking** system based on surface acoustic wave (SAW) tags will be developed and applied to monitor the ladle positions in the steel plant.
Usual ID tags are built on the basis of semiconductors and degrade over time when exposed to elevated temperatures, which is the reason why they cannot be used to track the constantly hot steel ladles. The approach to use high-temperature resistant passive SAW tags for steel ladle tracking is quite new, but SAW tags were tested in some first similar applications, e.g. at slag pots and slide gate plates [17-20]. Therefore a lot of work will have to be done to develop reliable ladle tracking set-ups capable of coping with the harsh working conditions in a steel plant.
For tracking ladles, the set-up illustrated in **Figure 2** will be used: A reader unit and active antenna form the receiving station to be placed at different positions in the steel plant. The SAW sensor with its passive antenna is attached to the steelmaking ladle. As soon as the sensor is near the active antenna, the incoming signal will be transduced from electric impulse into a surface acoustic wave. The wave propagates along the surface and is reflected by a mirror. Afterwards it is transduced into an electric impulse and emitted by the passive antenna. The ID coding is realised via the runtime.

In order to define the optimal positions for SAW tags at the ladles, and for antennas and readers in the steel plant, plant trials will have to be performed. The SAW tags mounted on the ladle shell will have to cope with the different conditions of space and temperature at the various treatment stations. For that reason protective devices for the selected SAW tags, but also for antennas and readers, will be designed and constructed. In order to receive the ladle IDs, antennas have to be arranged with regard to the transmission range: as near as possible to the SAW tags of ladles passing by and far enough to be safe from impacts by ladles or cranes.
The SAW tags allow digital, online and fail-safe identification of the ladles exactly on arrival and departure at the individual treatment stations throughout the steel production chain, from steelmaking via secondary metallurgy to casting, and also at the stations for ladle repair and preheating.

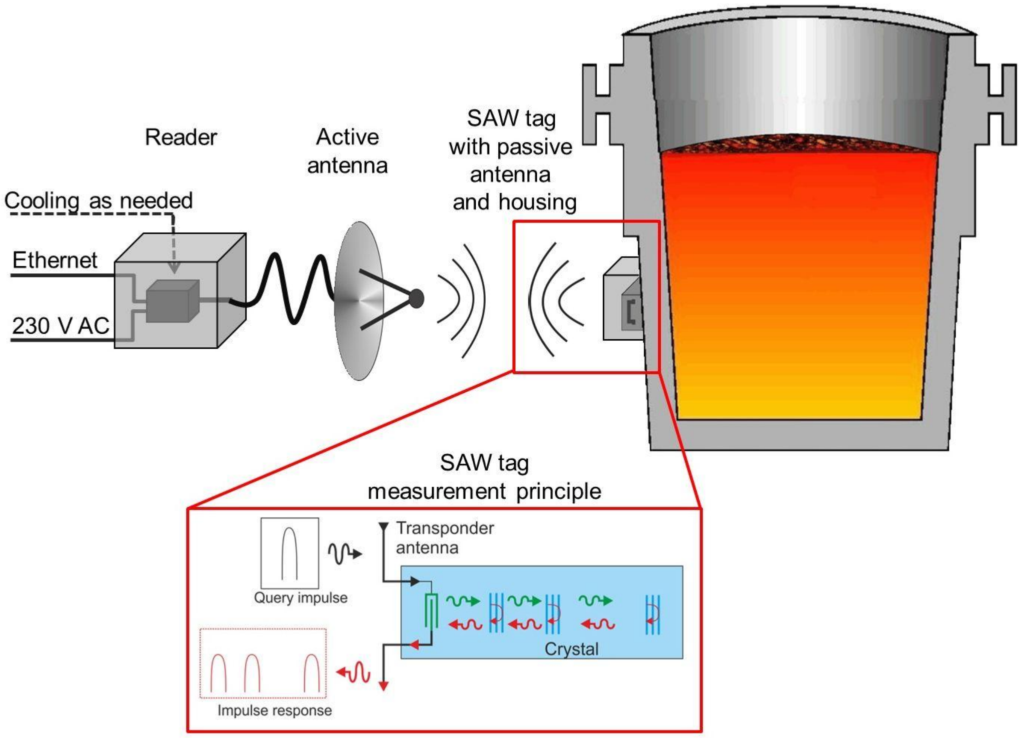

Figure 2: Schematic set-up of ladle tracking system and operating mode of SAW tag

The automated ladle tracking system will allow the immediate detection of deviations from the planned heat and ladle schedules, e.g. unforeseen events as delays, plant equipment failures. The deviation detection system will be based on a constrained factory model together with the knowledge of the operation plan of the steel plant. This model will be kept synchronised with the real state using the collected information in an event-driven way (e.g. for the ladles but also from other available sensors). When an event triggers some violation with respect to normal operation or planning constraints, a deviation event will be triggered and will be processed by a recovery system that will compute a possible sequence of operation that maximizes the delivered value given the encountered deviation and the current state of the factory. It can for instance try to get back to the planned schedule. The best technical solution will be designed based on available state of the art algorithms (like [24-26, 29]). Open Source solutions (like OscaR [27]) will be considered provided they prove their ability to scale on industrial problems, maturity and ease of integration.

Finally data analysis and mining algorithms (as in [36, 37]) will be applied to enable continuous improvement of the tracking system by characterizing its weaknesses from historical data collected during its operation, and enhance logistics optimisation by improving the accuracy of the timing estimates of ladle movement. Data analysis will be also employed for gaining knowledge on the relation among product quality and process-related settings in order to point out eventual improvement opportunities. Analysis will be performed using BigData software tools and programming frameworks in order to be able to process huge volume of data (for example long time series) from a large variety of data sources and formats and, if necessary at high velocity. BigData tools will apply machine learning algorithms on data.

4. Outcome

The overall objective of the Pilot & Demonstration project is to implement consistent factory-wide tracking of the ladles in use in the steel plant from tapping to casting. The through-process tracking of the ladle can only be accomplished with an automated system that reliably monitors the movement of the ladles and delivers online feedback about ladle positions to the process control and production scheduling systems. This is mandatory for realising a continuous and reliable tracking of the product throughout the whole production process. Innovative sensors and instrumentations will be applied to follow the ladle along the complete production chain even at different factory workshops from tapping of the liquid steel via several ladle stations in secondary metallurgy to casting of the liquid steel melt.
The following aims shall be achieved by implementing the automated, wireless tracking system in the harsh steelworks environment:

- Providing mandatory input data for further projects on digitalisation and integration of complex industrial production chains as in steelworks (“Industry 4.0”)
- Improving the **safety** in steelworks by avoiding accidents due to ladle mix-up.
- Increasing the **factory output** as hold-ups in the production plan or downgrading of products due to mix-up of ladles can be avoided.
- Improvement of production planning by providing more reliable information on the actual position of ladles, either being treated, in transfer or on stock.
- Optimisation of short-term transfer by evaluation of ladle transfer patterns and the time elapsed for transfer and treatment.

The benefits, which are expected from the results of the project, affect the productivity of the steel plants. Only reliable and automated tracking of steelmaking ladles provides consistent tracking of the product from tapping to packaging and will therefore support the realisation of further projects on digitalisation and integration of complex industrial production chains as in steelworks (“Industry 4.0”).
Besides this, the following economic aspects and benefits shall be mentioned:

- The establishment of a wireless ladle tracking system will lead to accurate identification of steel ladles and prevent ladle mix-up. This will result in:
  - Avoiding accidents due to using the wrong ladle for a process, for example tapping into a wet ladle. It is estimated that several dangerous situations per year occur in every European steelworks, some of them ending in fatal accidents [5].
  - Enhancing the certainty of casting the desired steel grade. Thus, hold-ups in the production process and the necessity of downgrading a steel melt will be reduced. Especially in large integrated steelworks operating several casters in parallel this situation is well known.
  - Avoiding damage to facilities due to inappropriate utilisation. Severe damages after tapping in a wet ladle require big repair effort. Casting of a wrong steel grade (due to ladle mix-up) may result in strand break-out.
  - Saving energy and time by preventing unnecessary movement or prolonged stay of a hot ladle. Depending on ladle size and coverage, liquid steel temperature loss is in the range of 0.5 K/min to 3 K/min. A complete reheating of the steel melt at the ladle furnace due to a too cold ladle delivered to the tapping position requires an additional electric energy input of up to 50 kWh per ton of liquid steel. Also the casting sequence will be disturbed or even has to be stopped when the heat is delivered with a significant delay caused by prolonged heating requirement at the LF.

- With the tracking system it will be possible to visualise ladle motion patterns to identify, document and prevent bottlenecks.
- The ladle tracking system provides a reliable data basis for dynamic process models and production scheduling systems. Investigations on previous process disturbances or interruptions can rely on a dependable data source.
- Many customers related to automotive industry are getting more exigent with respect to product tracking in order to check possible quality issues. Improving tracking performance will allow the companies being up to the expectations of their customers and in consequence maintaining competitive ability.

References

Previous EC, ECSC or RFCS projects

[P1] Factory-wide and quality-related production monitoring by data-warehouse exploitation (FACTMON)
RFCS project RFSR-CT-2003-00041 (2003 – 2006)
The concept of factory-wide production monitoring system was studied in this project. Three different solutions were investigated for a tinplate line, from the production stages to the finishing lines and for the annealing and pickling line for stainless steel black coil. Using multivariate statistical process control (SPC) techniques the work efficiency of the engineering staff could be increased.

[P2] Optimization of stocks management and production scheduling by simulation of the continuous casting, rolling and finishing departments (SIMUSTEEL)
RFCS project RFSR-CT-2005-00046 (2005 – 2008)
The project dealt with the development of a software tool which implements a method to solve problems in the production flows of a modern steel plant. The tool consists of schedulers and simulators of the flows of materials, the schedulers formulate the best production plan, while the flow simulators are used to validate the plan.

[P3] Improving steelmaking processes by enhancing thermal state ladle management (LADTHERM)
RFCS project RFSR-CT-2014-00006 (2013-2017)
The project aims to monitor the thermal state of steelmaking ladles during secondary steelmaking operations and to improve said operations. Improvements are derived from optimised utilisation of the heat stored in the ladle lining. Innovative temperature measurements in the ladle refractory provide online information to accompanying thermal models, calculating the actual total ladle heat content Q that is stored in the lining.

[P4] Intelligent PPE system for personnel in high risk and complex environments (I-PROTECT)
EU project FP7-NMP 229275 (2009-2013)
The objective of the project is to develop a personal protective equipment system that will ensure active protection and information support for personnel in high risk and complex environments. Within this project sensors for monitoring physiological parameters or environmental parameters and communication to a coordination centre were developed.

[P5] Surface Acoustic Wave wireless sensors for High Operating Temperature environments (SAWHOT)
EU project FP7 NMP4-SL-2009-247821
The objective of the project was to develop an innovative wireless system capable to measure physical parameters in a wide temperature range (-20 °C to +650 °C). This development is based on Surface Acoustic Wave (SAW) sensors which are passive devices with a specific high quality substrate and equipped with specific antennas, read-out system and interrogation strategy customised for high temperature environment. The sensors were exposed to ambient temperatures up to 800 °C, and temperature readings were possible up to 700 °C.

[P6] Multi-criteria through-process optimisation of liquid steelmaking (TOTOPTLIS)
RFSR-CT-2010-00003 (2010 - 2013)
Main objective of this project was the development of a through-process optimisation for the liquid steelmaking route, applied for two oxygen steelmaking and one electric steelmaking plant. Real-time monitoring and predictive models, using process and sensor data from different aggregates, were integrated for a multi-criteria optimisation of material and energy input regarding quality, productivity and costs. The achievable benefits from dynamic modifications of the planned process steps in case of deviations in quality relevant parameters have been tested within off-line case studies. Regarding ladle treatment, the focus was laid on a through process steel temperature model with consideration of the thermal ladle status. Regarding secondary metallurgy also control of desulphurisation, decarburisation and degassing were considered.

[P7] Technology-based assistance system for production planning in stainless mills (TECPLAN)

RFCS project RFSR-CT-2011-00040 (2011-2014)
The project aims at introducing and developing an assistance system that determines the optimal production route for stainless steel in steel processing plants. The system is based on measurements of strip flatness at different locations in the processing chain and the development of prediction models for quality parameters and plant throughput for different processing routes.

[P8] Development of a new automation and information paradigm for integrated intelligent manufacturing in steel industry based on holonic agent technology (I2MSTEEL)
RFCS project RFSR-CT-2012-00038 (2012-2015)
The objective of this project was to develop a completely new paradigm for steel specific, factory- and company-wide automation and information techniques. Therefore agent based software technologies were applied to give each product and each plant a kind of intelligence. On this way the usually centralized planning was replaced by a decentralized planning and optimization. Production scheduling is one application field in which the new paradigm can bring significant improvements.

[P9] Development of tools for reduction of energy demand and CO_2-emissions within the iron and steel industry based on energy register, CO_2-monitoring and waste heat power generation (ENCOP)
RFCS project RFSR-CT-2009-00032 (2009-2013)
This project introduced a holistic approach to minimize the energy consumption and CO_2 emissions in integrated iron and steel plants. A Decision Support System including a set of software tools was developed to monitor and improve process performances. A model of the plants which are more relevant for the CO_2 emissions were developed and exploited within a Multi-Objective Optimization (MOO) framework in order to optimize the off-gases distribution among the different internal and external consumers: Mixed Integer Linear Programming (MILP) and Genetic Algorithms (GA) based MOO approaches were applied.

[P10] Efficient use of resources in steel plants through Process Integration (REFFIPLANT)
RFCS project RFSR-CT-2012-00039 (2012-2015)
Within this project the problem of optimization of by-products and water reuse was faced by exploiting an approach based on Process Integration solutions. Within the project, a software tool for developing and optimal layout and stream distribution in water circuits was developed, which exploits Multi-Objective Optimization (MOO) techniques. Moreover an existing software tool with embedded MOO capabilities was exploited for the analysis of optimal by-product distribution and reuse.

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