THE USE OF HIGH FREQUENCY RADARS TO ESTABLISH A RELIABLE AND ROBUST COKE OVEN MACHINE POSITION CONTROL SYSTEM[1]

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Abstract
Modern automation and instrumentation technology solutions encounter a variety of difficulties related to installation at the extremely harsh coke oven plant environment. Such problematic issues as high temperatures, spillage coke, coke dust and quality of foundation civil works present very high demands for maintenance as well as applicable automation solutions with reliable operation. This paper evaluates the problematic issues related to achieving the highly accurate positioning sequence of heavy machinery in the harsh coke oven plant environment. As presented in this paper, the solution consists of a bracketless and maintenance-free radar based positioning application. The benefits of a radar-based solution include reduced plant downtime (increased coke throughput), more efficient plant operations, reduced maintenance requirements, improved operational safety and numerous benefits related to system integration. The results of the latest R&D venture conducted jointly by Siemens Metals Technologies' Center of Technology for cokemaking and a reference coke oven plant are presented. The subject coke oven battery is a 25-year-old top charging battery consisting of 72 ovens. During the R&D project, redundant radar based measurement along with Siemens' intelligent SIMETAL Coke Radar application software was implemented to all of the machines at the subject coke oven battery. The results show that an average positioning accuracy of ±1,2mm and a maximum deviation of ±5mm was achieved. In addition, it was confirmed by the reference plant representatives that the radar based system is suitable for primary means of positioning and continuous operation in the coke oven plant environment.
Keywords: Coke oven machine; Radar; Positioning; Interlocking.

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1 INTRODUCTION

In controlling the operation of coke oven battery one of the main objectives is to have fast, reliable and accurate positioning and interlocking of the oven machines, in the harsh environment of a coke oven battery. Misalignment of rail tracks, high temperatures, dust emissions and spillage coke are some of the problematic factors in the coke oven plant environment, which require robust solutions with tailor made technology in order to achieve successful implementation. Stable and disturbance free operation of the machines is a must, while aiming towards stable process control and effective coke production.[1]

The radar based coke oven machine positioning and interlocking solution has been specifically designed to survive in the demanding conditions of a coke oven battery and it combines all of these features. The solution also reserves the possibility of integration into various other automation systems of the coke oven plant to store measured process parameters from the mobile coke oven machines.[1]

Experiences from tens of installations worldwide, by Siemens, in the field of coke oven machine positioning and interlocking has shown that due to successful operation of this technology the positioning accuracy and operational safety through interlocks has been improved. By means of higher automation level of the coke oven machines, the operation of the machines can be stabilized. This also leads to more stable coking times of coke ovens. The state-of-the-art technology used by Siemens' radar based solution is bracketless and maintenance free and hence more tolerant to the constant disturbances in the coke oven plant environment.[1]

The objective of this paper is to reliably indicate that sufficient positioning accuracy of coke oven plant heavy machinery can be achieved with the use of bracketless radar based position measurements. In addition, the radar instrumentation is expected to withstand the extreme conditions of a coke oven plant environment with very low maintenance requirements.

2 MATERIAL AND METHODS

2.1 Background

The pushing and charging operations at a coke oven plant are carried out by heavy machinery travelling on rail tracks alongside the coke oven battery. In order to carry out the mobility functions of these machines automatically, instrumentation has to be implemented to position the machines accurately in front of each of the ovens of a coke oven battery. The general perception of the positioning accuracy requirement for automatic machine positioning is ±5mm.

Smooth and disturbance-free operation of the coke-oven machines is a key factor for efficient and economical cokemaking operations.[2]

2.1.1 Charging operation

There are a number of techniques for charging coke ovens with pulverised coal (80 – 90 % of the pulverised coal is <3.2 mm) through the charging holes. The most common technique is gravity charging by charging cars. The charging process starts by lifting the first charging hole lid and finishes with closing the last charging hole. The whole procedure takes about 2 to 3 minutes, whereas the charging process itself takes about 45 to 60 seconds, depending on the size of the chamber. This can be simultaneous, sequential or stage charging by speed controlled horizontal screw

feeders or turntables. Other systems like pipeline charging or stamp charging are also applied.[3]

2.1.2 Pushing operation

Fully-carbonised coke is pushed out of the oven into a container by the ram of the pusher machine usually in less than one minute (see Figure 5.7) [223, USEPA 2001] through a coke guide car (transfer machine) into a 'coke quenching car'. Contact with atmospheric oxygen causes the coke to start burning instantaneously.[4]

2.2 Description of the Radar Based Positioning and Interlocking System

The radar based positioning system features a two radar sensors per machine installed onboard all of the coke oven machines in operation, as well as two radar sensors installed at the end points of rail tracks for each coke oven machine. Both of the so called radar pairs continuously measure the distance between the static reference point and the moving machine.

The system is fully integrated to the existing coke oven battery PLC system and the coke oven machine PLC systems. Implementation of the radar based system requires only the installation of communication modules to the existing PLC systems of a coke oven plant in order to transfer the measurement data from the radar instruments to the static coordination PLC.[1]

During the installation and commissioning of the system, distances of individual ovens are predefined in the PLC memory. Oven identification is then done by comparing the distance measured by the radar sensors with the predefined distance of that particular oven from a reference point. Interlocking of the coke oven machines across the coke battery for pushing and charging operations is executed over wireless communication links installed in each of the coke oven machines (alternatively RF communication or WLAN link can be used).[1]

The radar system features the possibility for automatic operation (with operator intervention) or manual operation. The open architecture of the subject system allows the user to modify and maintain the system independently in case major changes occur in the mechanical structure of the coke oven battery (i.e. slight misalignment of machine rails or oven positions over a period of time).[1]

Illustration of the system structure is presented in Figure 1.

The radar based positioning system can be applied to all types of coke oven machines including pusher cars, charging cars/stamping machines, coke guide cars/transfer cars and quenching cars/hot coke bucket cars. At the minimum, the following interlocks between the machines are established by the solution:[1]

- Machines are at the right position
- Machines are in front (or top) of the right oven
- Machine stays between the set limits
- Oven identification number is correct
- Doors are open
- Collisions between machines are prevented

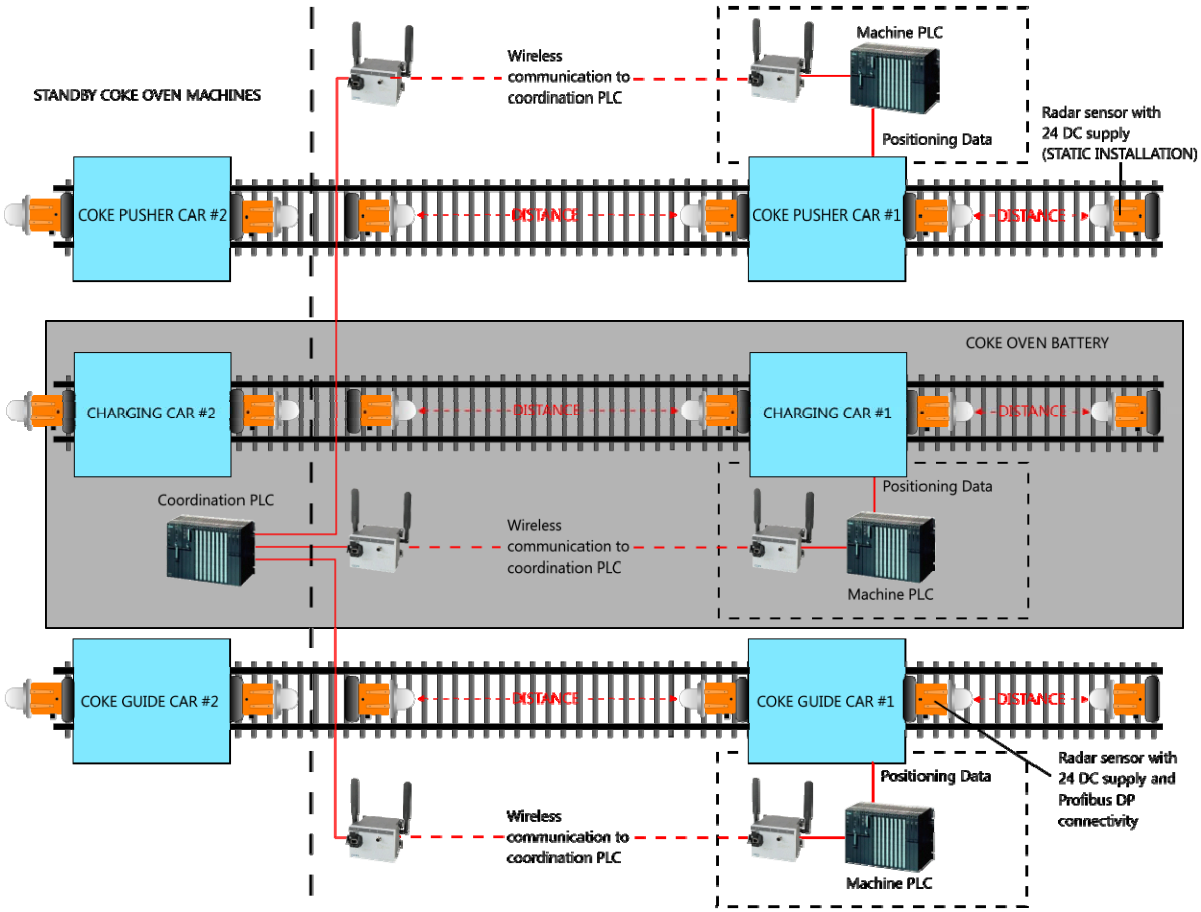

Figure 1. Radar based system configuration.[1]

The coke oven machine PLC gives speed reference signal (full speed, normal speed, slow down speed, braking speed) to the travel drive control i.e., frequency converters of the coke oven machine. This indication is also seen on the machine HMI. The operation of radar based positioning system includes the following sequences:[1]

1. After all activities of the previous pushing have been completed, the information on the next oven to be pushed is sent over the wireless communication link to the coke oven machine PLC. This data is shown on the user interface of the machine. The operator accepts this information by using a soft push-button, located on the HMI of the system.[1]
2. Next movement of the machine has been initiated and the operator follows the actual machine position on the machine HMI. [1]
3. When the machine approaches the right oven, the system initiates the slow-down sequence in order to reduce the machine movement rate to so called creep speed. [1]
4. The predefined oven number read by the oven identification system, is displayed on the machine HMI. [1]
5. In case, a coke oven machine overpasses the stop point (for such mechanical reasons as wheel slip, back lush of gear box etc.) the repositioning sequence of the system is initiated. This function ensures an accurate positioning and interlocking of the coke oven machines in all operating conditions for pushing and charging. [1]

For the interlocking the sequence continues as follows:

6. According to the pushing/charging operations, the PLC system checks if the oven number and conditional interlocking signals match with the status of the other coke oven machines across the battery. Once the interlock matches, the system gives indication to the operators to initiate the pushing/charging sequence. (1)
7. For next operation, the positioning and interlocking sequence above is repeated.

2.3 Description of the Wireless Communication System

Wireless communication links are used to transfer data between the coke oven machine PLC systems and the coke battery PLC system. This wireless communication transfers data from and to the coke oven machines. In the case of WLAN communication, directed WLAN antennas are used to counter any disturbance to the communication signals. (1)

All of the communication equipment such as the routers, antennas etc. are designed for use in demanding local area data communication applications in industrial environments. The routers provide flexible data transfer between fixed and mobile stations. The system is typically constituted of one master station and several slave stations. In case of two sets of coke oven machines for one top charging coke battery, the configuration is as follows: (1)

• Master station:	Coke battery	1 set
• Slave stations:	Pusher car	2 x 1 set
	Charging/Stamping machine	2 x 1 set
	Coke guide/Transfer car	2 x 1 set
	Quenching car	2 x 1 set

The data messages, which are required for successful operation of the radar based positioning system and sent between Coke Oven Machines PLC system and Coke Battery PLC system, use the same basic message format. When a data is received, a checksum is calculated and compared with the checksum in a message. In case of difference, the data will not be accepted. In case of error, the message will be repeated. (1)

For interlocking, the safety and efficient operation of the coke oven machines require certain information to be exchanged over the wireless link. The following are the broad grouping of these data messages: (1)

- Machine grouping
- Pushing interlock
- Charging interlock
- Quenching loco movement synchronization with the pusher
- Additional data transfer

2.4 Functional Performance Test Procedure of the Radar Based System

To illustrate the research and development project results, at the reference coke oven plant, a functional performance test for the radar based positioning system was carried out. The tests took place on January 17th 2013 and were carried out on a 25-year-old automated pusher machine. (5)
The functional test procedure was the following:

1. The objective of the test was to separate radar position measurement accuracy from the overall positioning accuracy, which is the total result of mechanical-, electrical- and radar system accuracy. (5)
2. Position of the machine during the test was defined by two ways after each positioning trial. The first measurement was the actual position of the machine measured at battery bench level and the second measurement was the position of the machine indicated by the radar positioning system. (5)
3. First, the target points were defined at two locations. The first one at the east end of the coke oven battery block no.1, and the second one at the middle of the two battery blocks (oven no. 33). The locations of these target points were 587 256 mm and 453 233 mm respectively i.e. the distance between the two points was 134 023 mm = 134,023 meters. (5)
4. The positioning sequence of the pusher machine, using radar based positioning, was repeated 20 times; 10 times from east to west and 10 times from west to east. (5)
5. After each positioning trial, the position of the machine indicated by the radar measurement was recorded and the difference to the defined target value was calculated. (5)
6. The measurement result of the radar was deducted from the result at bench level. This value represents the accuracy of the radar based system eliminating any random error coming from mechanical and electrical features of the machine itself. (5)
7. In this particular test procedure the radar measurement and the manual bench level measurement were considered as independent from each other. The measurements were carried out simultaneously by two different persons not in communication with each other for the duration of the tests. (5)

Test conditions: Weather was clear, temperature -22 °c, no wind. (5)

3 RESULTS

The following results of the functional performance test according to the procedure described in Chapter 2.3 of this paper were obtained from the reference coke oven plant's pusher machine. The representatives of the reference plant have confirmed the validity and correctness of the results:

Table 1. Radar based system functional performance test results 17.01.2013

	Unit	Trial from west to east	Trial from east to west
Number of trials	pcs	20	20
Average difference between measured values and radar measurement value	mm	0,75	-1,75
Standard deviation	mm	2,63	1,97
Maximum error	mm	5	4

Referring to the above results, it should be further noted that the he positioning accuracy represents only the accuracy of the radar based positioning system. The error caused by mechanical and/or electrical errors may be significant, but can be minimized by proper design, calibration and disciplined maintenance of the plant and machines.
According to the OEM, the radar instrument accuracy is on the level of ±10mm[(6)], however as seen from the results, due to implementing a redundant measurement and Siemens' intelligent SIMETAL Coke Radar application software, the accuracy can be increased significantly from the manufacturers indication.
Figure 2 represents the installation of a single high frequency radar pair.

Figure 2. Static- and onboard radar installation.[(1)]

4 DISCUSSION

Due to the innovative nature of the topic of this paper, there are not many radar based coke oven machine positioning systems on the market, and even less publications of such systems. However, there are various systems for positioning and interlocking of coke oven machines by means other than radar based measurement.
Alternative means of automatic positioning include, RFID-, magnetic-, proximity-, photocell- etc. based systems. The common factor in the alternative positioning systems is that in order to accurately position the coke oven machine in front of each oven and furthermore identify the oven number, mechanical installation brackets for each sensor are required. In plants with hundreds of ovens, this corresponds firstly to heavily increased installation and erection costs and secondly to high maintenance requirements.

In realized installations of the radar based positioning and interlocking system, it has been noticed that mechanical engineering, installation, erection and commissioning times required have been reduced by 30-40%. In addition to this, in the harsh environment of the coke oven plant, sensors installed at the bench level require maintenance attention (cleaning) typically once every shift. The subject radar sensors at Siemens' reference plant have been installed up to 8 meters above the bench level, and until today the radars have been continuously in operation for more than 12 months with zero maintenance requirement (despite the coke plant problematic factors such as excess heat, spillage coke, machine rail misalignment etc.).
The above mentioned benefits combined with the more than sufficient accuracy of the radar sensors (average ±1,25mm achieved at performance tests) up to a distance of 500m,[(6)] makes the radar based positioning and interlocking system one of the most simple and robust system on the market catering to the needs of coke oven plants with strictly limited investment budgets, limited maintenance manpower and a demand for a reliable coke oven machine position control system.

5 CONCLUSIONS

As stated in the very beginning of this paper, smooth and disturbance-free operation of the coke-oven machines is a key factor for efficient and economical cokemaking operations. The reliability and accuracy of the radar based coke oven machine position measurement has been proven at Siemens' reference coke oven plant to be at a very high level with minimum maintenance effort taking into consideration the variety of problems arising from the coke oven plant environment. In cases where the initial coke oven machine positioning has been fully manual, Siemens has been able to increase the coke throughput of the plant by up to 2% without reducing the coking time of the ovens. These results have been simply achieved by implementing an optimized pushing- and charging schedule and automating the coke oven machine movement with means of radar instrumentation.
The interlocking feature of the radar based positioning system further decreases the time consumed by the coke oven machine operations and most importantly contributes to operational safety by preventing coke oven discharging when all the machines are not in the correct position.
The significant reduction in the amount of instrumentation and sensors required for heavy machinery to position accurately along the coke oven battery, makes the radar based system a simple enough solution to reliably operate at a coke oven plant environment without regular maintenance. These features of the radar based system open a lot of possibilities for the future to further optimize and automate coke oven machine movements all the time moving towards reliable fully unmanned coke oven machinery.

REFERENCES

1 I. Veijola, A. Kellin and O. Ritamäki, *Siemens VAI, SIMETAL Coke Radar Technical Specification*
2 I. Veijola, A. Kellin and O. Ritamäki, *PUMAS, the Coke Oven Watchcat,* Metals & Mining Magazine 01/2011, p. 32-35
3 European IPPC Bureau, *Best Available Techniques (BAT) Reference Document for Iron and Steel Production, p. 210*

4 European IPPC Bureau, *Best Available Techniques (BAT) Reference Document for Iron and Steel Production, p. 213*
5 O. Ritamäki, *Siemens VAI, SIMETAL Coke Radar Functional Performance Test Certificate, p. 1-2*
6 SYMEO Absolute Positioning, *Technical Data Sheet, High Precision Distance Measurement, p.1-2*