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

TrackOpt

Public

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Deliverable 1.1 – Suitable ladle tracking set-up selected and tested under working conditions in the steel plant

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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. Test and selection of suitable ladle tracking set-up

This chapter describes the activities regarding test and selection of components for a ladle tracking system based on Surface Acoustic Wave (SAW) sensors. For a description of the SAW sensor system please see Deliverable 5.1 (Comprehensive overview), chapter 3, whereas **Table 1** summarises the advantages and disadvantages of a SAW sensor system.

Table 1: Advantages and disadvantages of a SAW sensor system

Advantages	**Disadvantages**
Insensitive to dust and smoke	Sensitive to other WLAN sources in same frequency (2,4 GHz)
Withstand temperatures up to 400 °C (compared to RFID based sensors with maximum operating temperatures of 85 °C (125 °C military specification))	Range (operation distance) and lifetime of SAW sensor decrease with increasing temperature (as at steelmaking ladle)
Insensitive to electromagnetic field of Electric Arc Furnace	

1.1 Laboratory trials

In preparation of laboratory trials to define optimal combinations of antenna systems, readers and SAW tags for best transmission conditions, the following measures were taken:

- Selection of four promising active antennas in terms of suitable band width, high gain (-> high distance) and robustness:
  - Small horn antenna
  - Large horn antenna
  - Flat panel antenna
  - Grid antenna
- Comparison of readers:
  - Industrial reader
  - Fast reader
- Comparison of SAW sensors:
  - SAW slot sensor
  - Reinforced sensor

The results of the laboratory trials (**Table 2**) performed at BFI to define the optimum combination and to test the pre-selected antennas are presented in **Figure 1**.

Table 2: Description of laboratory trials

Trial number	**Antenna type**	**SAW tag (sensor and passive antenna)**
P1	small horn	SAW tag
P2	small horn	SAW tag on sheet
P3	large horn	SAW tag on sheet
P4	large horn	SAW tag on sheet with side panels
P5	flat panel	SAW tag on sheet with side panels
P6	grid	SAW tag on sheet with side panels

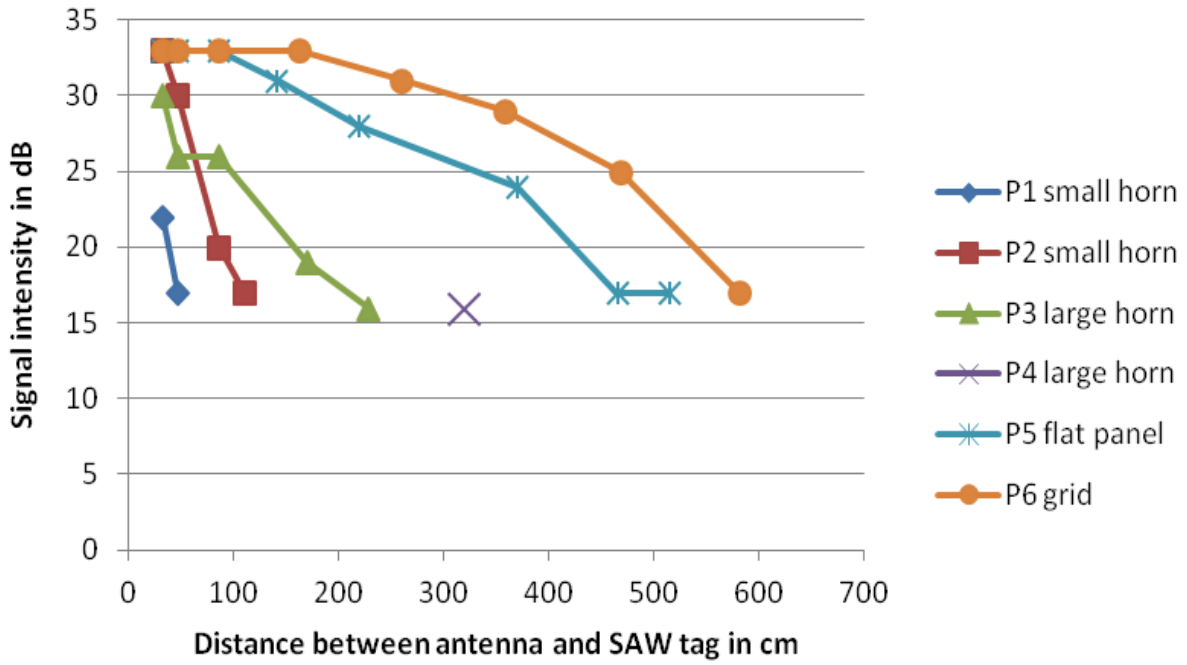

Figure 1: Results of laboratory trials: Signal intensity of different antennas against distance between antenna and SAW tag

Maximum distances were achieved with grid and flat panel antennas, but these antennas are most likely capturing stray radiation. The large horn antenna could be the best compromise regarding range (operating distance), thermal resistance, capturing stray radiation and serviceability.
Based on the laboratory trials, two antennas were chosen for industrial trials: Large horn and flat panel antenna.

1.2 Mounting position for SAW tag at steelmaking ladle

To define the optimal mounting position of the SAW tag at the steelmaking ladle of FENO, several aspects have to be considered:
The ladle is moved from one treatment station to the next either by ladle car or by crane. In a ladle car the lower mounting positions are shielded. Furthermore ladles are rotated and not always all parts are accessible.
SAW tags are made of ceramic material without any semiconductor, so they can withstand higher temperatures (up to 400°C) than standard RFID sensors with maximum operation temperature of 125 °C. But as indicated in Table 1, with increasing temperature of the SAW tag the transmission range decreases and the ageing accelerates.

At FENO, as at most steel plants, the upper part of the ladle is not suitable for mounting a sensor due to splashing (see **Figure 2** left and **Figure 10**). The lower part of the ladle is also not suitable due to shielding in ladle car (**Figure 2** right). Therefore, at FENO the SAW tag needs to be mounted:

- in the middle part of the ladle between the two reinforcement rings
- at the side of the ladle not facing the bottom during slag pouring to protect from heat radiation

Figure 2: Photographs of ladles in operation, showing splashing in the upper part (left) and ladle inserted in a ladle car (right)

1.3 Final selection of suitable components

The components (antenna system, reader, SAW tag) for the ladle tracking set-up that were to be implemented in plant trials were selected to be:

- Large horn and flat panel antenna
- Industrial reader
- SAW tag = SAW sensor with passive slit antenna mounted on a sheet with side panels for improved signal intensity

2. Plant trials for optimized mounting of ladle tracking set-up

2.1 Protection devices

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 a protective device for the selected SAW tag was designed and constructed. The SAW tag is mounted on a sheet with side panels. This is attached to a holder (**Figure 3** left) that was installed at the ladle shell during plant trials. To protect the holder and the SAW tag, the ladle was equipped with a 20 mm steel shield (see also **Figure 6** and **Figure 11**). Against radiation coming from other heating sources in the steel plant it is possible to install a mat of insulation material in front of SAW tag (**Figure 3** right), but this was not necessary during the performed trials.

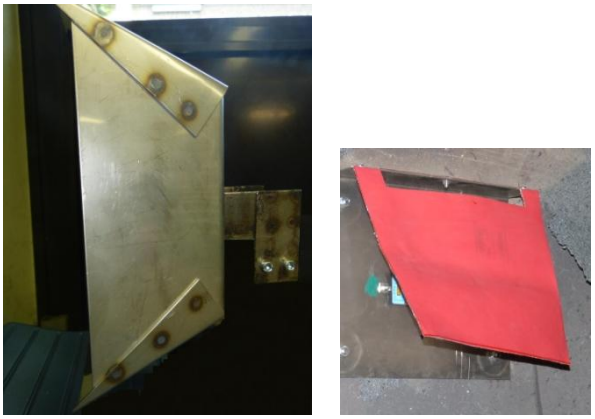

Figure 3: Holder for SAW tag (left) to be mounted to the ladle and exemplary image of mat of insulation material (right)

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. In a similar way to the SAW tag, steel and insulation protections can be installed on the antennas to prevent slag/steel splashing and overheating.

The SAW readers should be placed in a protection box (with electrical and LAN connections) to be protected against dust and high temperatures. Depending on the position of the reader, active cooling of the box might be necessary.

The cable connections from the antennas to readers and from readers to the PLC network must be shielded due to the exposition to high temperatures, and possible exposure to slag and dust. For example during an empty ladle travelling below a cable a light protection is needed (i.e. a fibre enhanced Marsoflex hose), and during a full ladle travelling below a cable a cooled steel pipe to pass the cables is necessary.

2.2 First campaign

During the first plant trials at FENO steel plant the ladle number 1 was equipped with the SAW sensor to evaluate the feasibility of the installation of a tracking system based on SAW sensors.

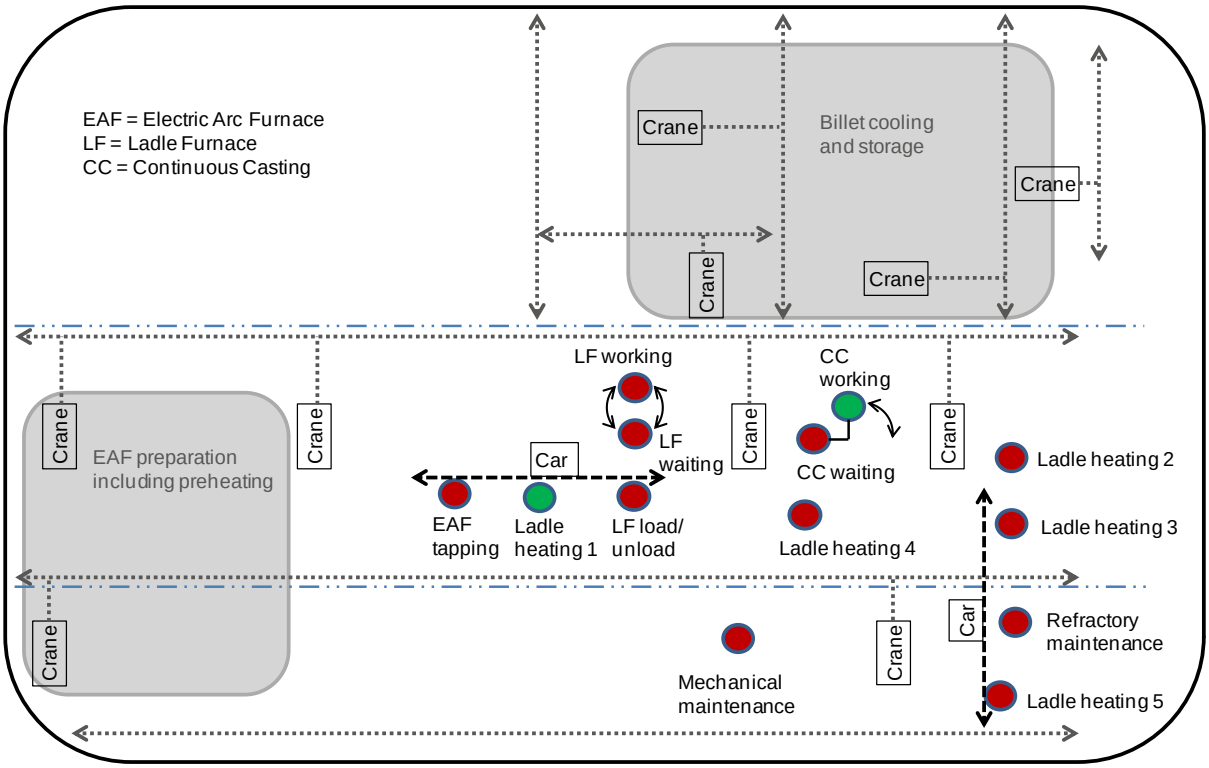

Figure 4: General map of FENO steel plant with possible read-out stations (red), tested read-out stations (green), cranes and ladle cars

The first installation regarded the waiting position of the ladle before the EAF tapping position (ladle on the ladle car under heater between LF and EAF), see **Figure 4** green station "Ladle heating 1".
During the trials flat and horn antennas were used to verify the differences of the signal strength.

Figure 5: Plant trial using large horn antenna with ladle (equipped with SAW tag) positioned in ladle car under heater

The first trial helped to prove the thermal and mechanical reliability of SAW tag, holder and shield. Ladles are working in a stressed environmental situation: The external temperature can reach 350 to 400 °C, and usually hot steel or slag splashing occurs. Additionally the ladle is moved by cars and cranes and is exposed to mechanical stress (deformation, bumping).

Figure 6: Visual (left) and infrared (right) images of ladle with SAW tag attached

To verify the heat resistance of SAW tag and protection FENO took a thermal image of empty ladle and filled ladle (**Figure 6**). The temperature measured on the SAW tag was between 110 and 180°C. This temperature could compromise the sensor's performance and reliability.

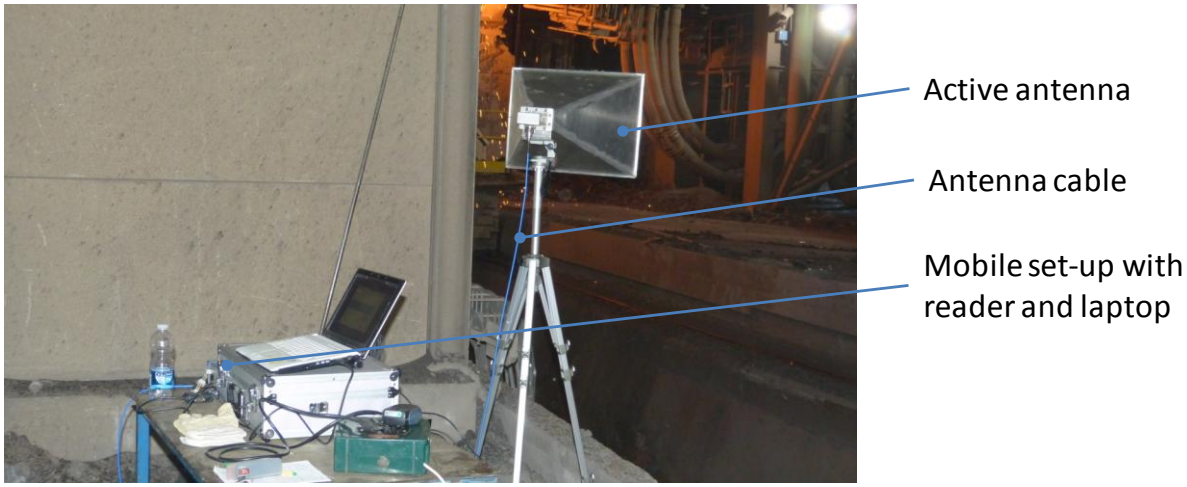

Figure 7: Trial equipment

The reading position was on a ladle car side, so for the BFI staff it was easy to move backward or forward the active antenna, to test the signal strength at different distances.

This reading equipment used consisted in antenna, reader, cabling and protection devices (**Figure 7**). The set-up was checked regarding positioning, protection devices and transmission range under working conditions.

During the first measurement campaign FENO and BFI conducted 7 trials, where different antenna types with different distances between SAW tag and active antenna were tested before and after tapping.

The results are summarized in **Table 3**.

Table 3: Results of first plant trial campaign

Trial number	Distance [cm]	Signal intensity, mean value [dB]	Antenna type	Process step: before/after EAF tap	Ladle heats tapped, treated, and casted before trial	EAF last temperature [°C]
1	380	26	large horn	before	17	
2	380	26	large horn	after	17	1604
3	315	16	flat panel	before	18	
4	315	18	flat panel	before	18	
5	215 320	16 21	large horn	after	18	1625
6	338 387 440 350	21 19 17 21	large horn	before	23	
7	350	25	large horn	after	23	1616

The comparison between flat panel and large horn antenna shows a better performance of the large horn antenna: The signal intensity was higher as well as the maximum distance between SAW tag and active antenna with stable signal for read-out of ID. The maximum distance achieved was 4,4 m.

Figure 8: Ladle waiting on horizontal heater – Very hard to place antennas

Monitoring of the ladle equipped with the SAW tag revealed that there are treatment stations in the steel plant of FENO where it will be very hard to place antennas, either due to open space and crane movements (**Figure 8)** or due to very restricted space, e.g. LF or casting machine turret (see also chapter 2.4).

2.3 Second campaign

During the further plant trials within a second campaign the ladle number 5 was equipped with the SAW sensor to evaluate the problems and the issues related to the position of the ladle in the turret of the casting machine (see **Figure 4** green station "CC working").
The sensor was installed in the middle part of the ladle to be visible by a large horn antenna positioned near to the railways of the tundish car (**Figure 9**).

Figure 9: Ladle with SAW tag at new position being inserted in CC waiting position with crane

The protection for the SAW tag was improved providing a new stainless steel holder and a new 20mm steel shield (due to the installation on higher position this was necessary to prevent slag/steel sticking coming from the top of the ladle) (**Figure 10** and **Figure 11**).

Figure 10: Slag sticking to ladle

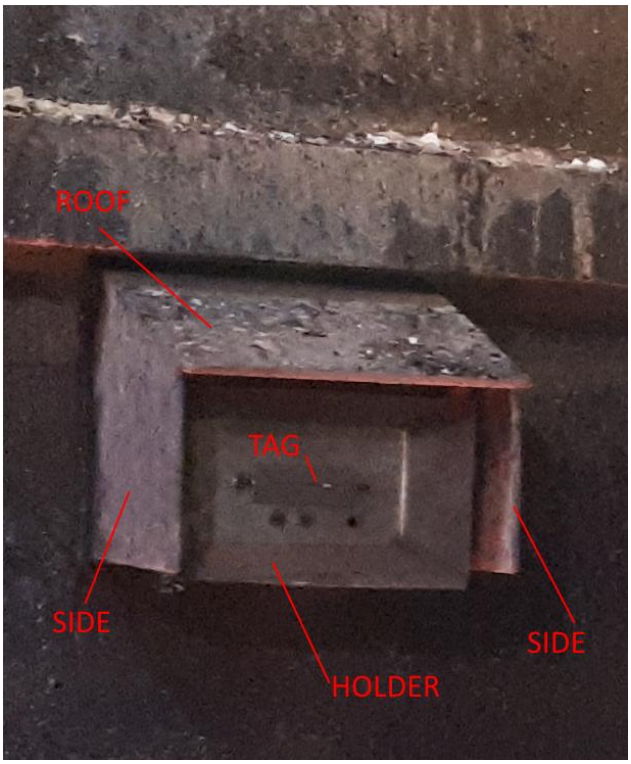

Figure 11: SAW tag (SAW sensor and passive antenna) on holder with shield after use

The new shielded box (roof+2 sides) was screwed up on the ladle shell leaving about some free air between the shield body and the ladle shell to prevent damages by the high temperature reached. The same approach was used installing the holder on the shielded box.

In this way the sheet with side panels has a double purpose:

- improve signal intensity and
- radiation shield.

During the second measurement campaign FENO and BFI conducted a trial with continuous tracking of the ladle using the equipment from the first trial, but only using a large horn antenna. The active antenna was aligned to the SAW tag at the ladle after the ladle arrived at the CC working position, and had to be re-aligned after movement (lowering) of the ladle (described below the figure) and after tundish exchange (done by car, where mechanical construction moves towards horn antenna).

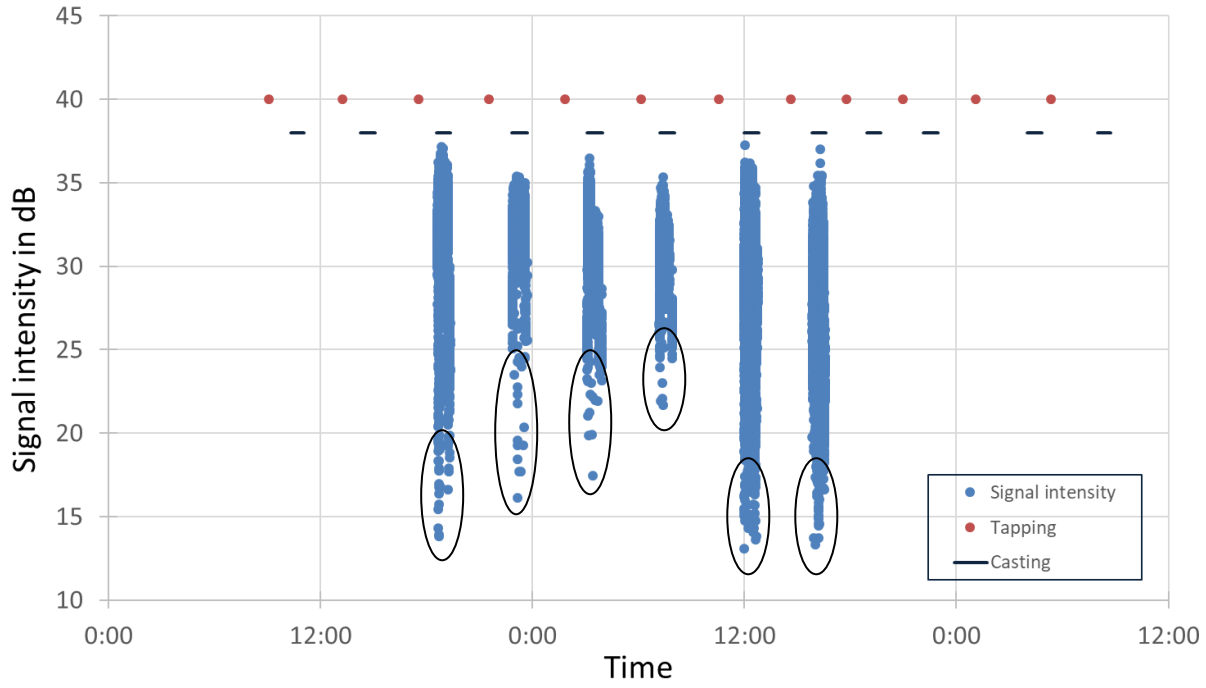

Figure 12: Results of second plant trial campaign: Signal intensity of different heats at continuous casting plant against time

The results in **Figure 12** show that all 6 heats casted between installation and demounting were recognised by the SAW system. The signal intensities plotted are the ones where the ID of the SAW sensor was correctly identified. They vary roughly between 15 and 37 dB. One of the reasons for this deviation is related to the movement of the ladle during casting, indicated by black ovals in Figure 12 (**Figure 13**). In FENO standard operations the ladle is risen up and lowered during casting, and during these movements the signal intensity varies and in worst case the read-out of the SAW sensor is not possible. The amplitude of the ladle movement is about 500 mm.

Figure 13: Movements of the ladle during casting

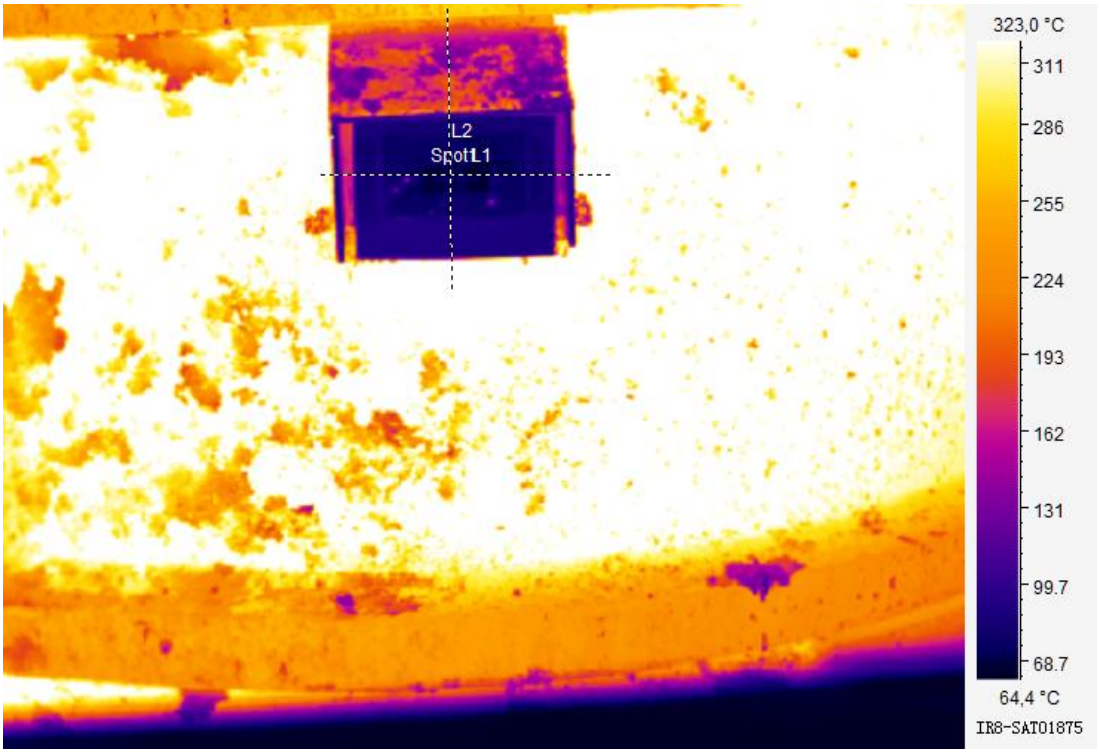

Figure 14: Temperature of the sensor/ladle during trials

As in the first campaign, to verify the heat resistance of SAW tag and protection FENO took a thermal image of the ladle during casting (**Figure 14**). The temperature measured on the SAW tag was about 60°C.

2.4 Layout of measurement equipment

To define the necessary measurement equipment in terms of numbers of SAW sensors, active and passive antennas, readers, cabling and protection devices, the whole production process at FENO had to be analysed.

Following one ladle in production process with SAW tag mounted as in first campaign revealed that read-out would only be possible at the three stations "Ladle heating 1", "LF load/unload" and "Ladle heating 2" (**Figure 15**). Read-out might be possible at the station "LF working" if space restrictions could be overcome. At the other stations read-out is not possible, caused by ladle rotation and tilting into horizontal position (e.g. at Ladle heating 3).

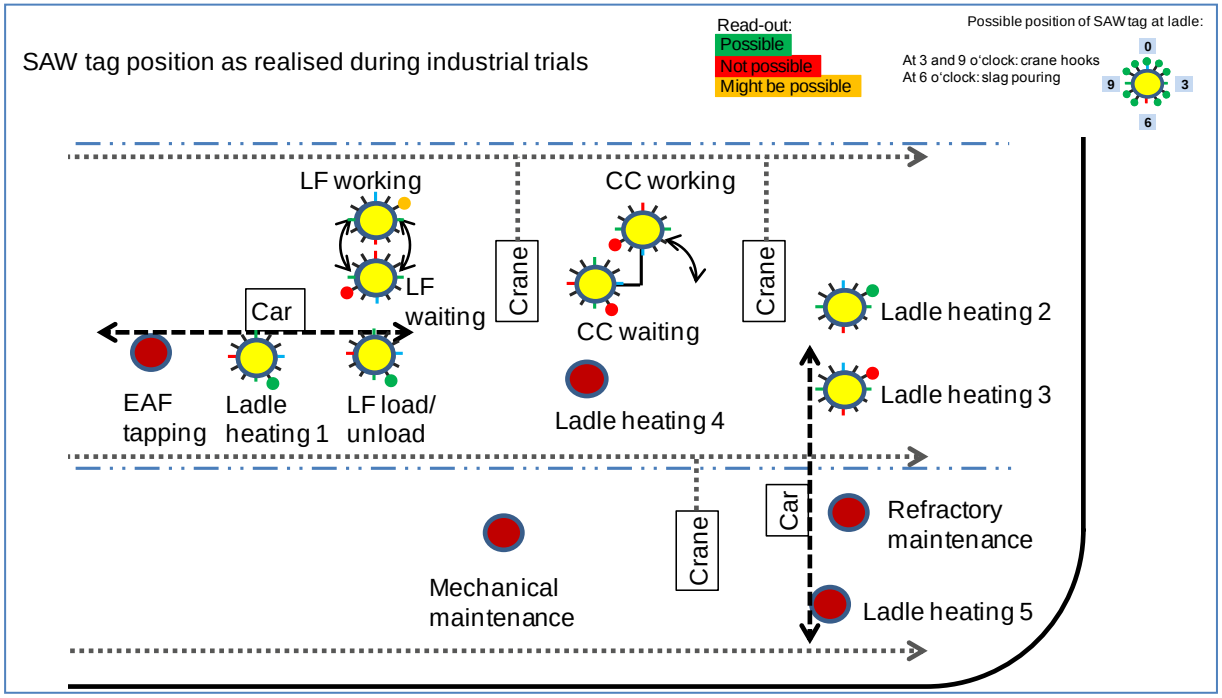

Figure 15: Overview of ladle with SAW tag mounted as in first plant trials (side A) and indication of read-out possibility

Mounting a second SAW tag on the opposite side of the ladle as in second trial campaign enables read-out at the station "CC working" (**Figure 16**). Figure 16 also shows the necessary positions for active antennas.

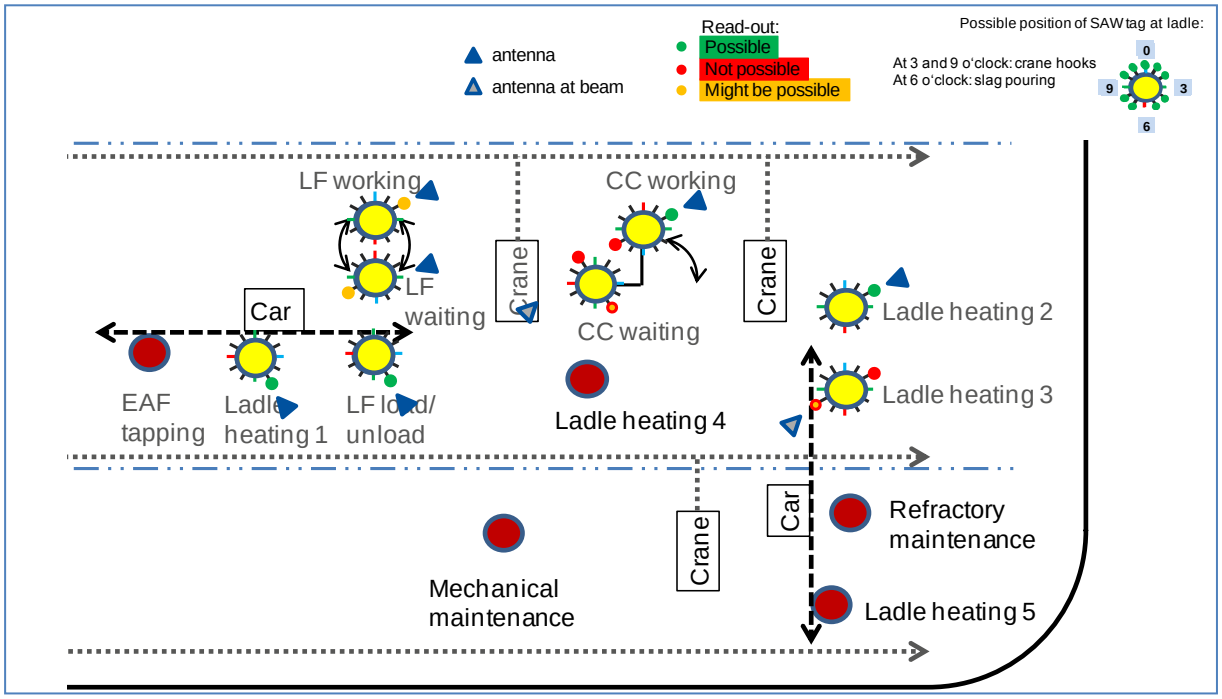

Figure 16: Overview of ladle with SAW tag side A, if necessary with SAW tag side B (opposite to side A), necessary antenna positions and indication of read-out possibility

After this first evaluation of possible read-out stations, FENO checked the stations regarding technical feasibility. The results are presented in **Table 4**.

Table 4: Overview over read-out stations at FENO and the read-out possibilities

Ladle station	*Read-out*	*Antenna type*	*SAW side*	*Reader no.*	*Notes*
EAF tapping	Not Possible	-	-	-	ladle ID defined by logic
Ladle heating1	Possible	Horn	A	1	
LF load/unload	Possible	Horn	A	1	
LF waiting	Possible	Horn	A	2	reader plus logic
LF working	Possible	Horn	A	2	reader plus logic
CC waiting	Not Possible	-	-	-	ladle ID defined by logic
CC working	Possible	Horn	B	3	
Ladle heating 2	Possible	Horn	A	4	
Ladle heating 3	Not Possible	-	-	-	ladle ID defined by logic
Ladle heating 4	Possible	Flat	A/B	5	difficult wire connection
Ladle heating 5	Possible	Flat	A/B	6	difficult wire connection
Refractory maintenance	Possible	Flat	A/B	7	difficult wire connection
Mechanical maintenance	Possible	Flat	A/B	8	difficult wire connection

To summarise:

- There exists no position for SAW tag at ladle which is accessible from all read-out stations.
- Installation of two SAW tags per ladle is necessary, 10 ladles at FENO -> 20 SAW tags

- 13 read-out stations were discussed, one not possible at all (EAF tapping due to harsh conditions), two might be possible if antenna could be placed at beams in steel plant, but not directly at positions (crucial: distance between antenna and SAW tag)
- Possibly, two combined read-out stations (two antennas connected to one reader) can be realised:
  - "LF load/unload" and "Ladle heating 1",
  - "LF waiting" and "LF working".
- Minimum 10 readers (8 listed in Table 4 plus 2 at beams) are required.

This will result in the following costs:
- Equipment costs (**Table 5**)
- Consumable costs (see below Table 5)

Table 5: Equipment costs

	Costs (single item)	**Costs (all items)**
20 tag holders	450 €	9.000 €
20 protection roofs at ladles	300€	3000€
12 (10) readers	~ 4.500 €	54.000 € (45.000 €)
12 (10) protection boxes for readers	min. 250 €	min. 3.000 € (2.500 €)
12 antennas	~ 1.100 €	~ 13.200 €
12 antenna cables	~ 240 €	~ 2.880 €
Sum		~ 85.000 € (~ 75.500 €)

Consumables:
SAW tags (sensor and passive antenna): ~ 150 € each
To equip all ladles, 20 SAW tags are necessary: ~ 3000 €
Each SAW tag needs to be replaced every 4-6 weeks due to degradation at the steelmaking ladle. This will cause additional consumable costs of 6000 to 9000 € per quarter plus additional maintenance effort for periodic replacement of SAW tags.

Due to the difficulties in technical feasibility of the realisation of read-out stations and the high follow-up costs for SAW tags and maintenance during operation, BFI and FENO discussed an alternative solution for automated ladle tracking.

2.5 Alternative solution

The alternative solution consists in a camera-based system for recognising the ladle (**Figure 17**).
Standard vision cameras can be used with a software for image recognition that gives the ID of the ladle. The ID can be a finger print plate welded to the ladle.
With this solution it is also possible to decrease the number of cameras (used instead of the antennas + readers) because one camera can catch the images coming from different ladle positions on the plant or have the same number of cameras with redundancy (i.e. cameras viewing similar positions on the plant, one camera covers LF turret and ladle car and the other camera covers LF turret. In this way, if the second camera has a fault, it is possible to track the ladle with the first camera).

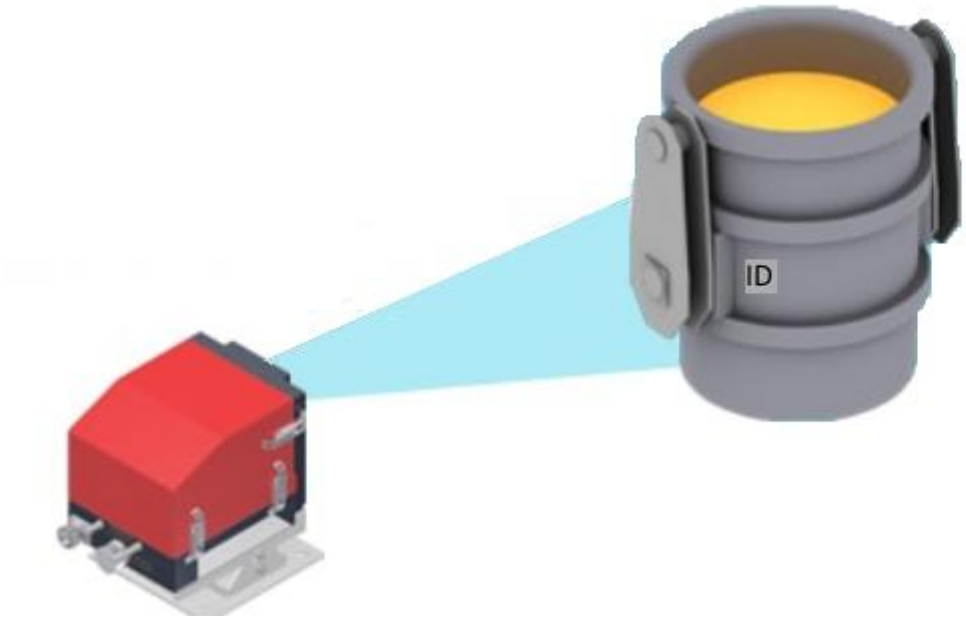

Figure 17: Sketch of alternative solution with ladle identification using cameras

The feasibility of the installation of this camera-based system is expected to be much easier, as cameras can have a greater distance to the ladles than the active antennas. Reliability and costs of purchase (cameras, recognition software, installation, Level2 process computer interfaces and modifications, wiring, plant modifying) is expected to be comparable to the SAW system. But with this alternative solution, the wear of consumables and maintenance effort is significantly reduced compared to the SAW sensor system as the ID plates are very robust and need to be replaced seldom.

3. Summary

With the first trial campaign it became clear that SAW tags have not such a long life time in the steel plant environment and their reliability doesn't completely satisfy the process requirements of FENO due to several issues:

- degradation of the SAW tags during operations,
- the necessity to place 2 SAW sensors at each ladle
- short distance needed between antenna and SAW

The biggest difficulty concerns the antenna installation, only 4 of 13 reading positions allow an easy installation.
As written before, in FENO process the ladle changes direction a few times during its working path and rotates during the positioning on the LF and CCM turret, so every ladle needs more than one SAW tag.

4. Next steps

Due to these disadvantages and the relatively high costs of the SAW sensor system it was decided by FENO to evaluate further the installation of the cameras and plates on ladles, provide the infrastructure and the connection to our process database. Finally FENO will be ready to get information about the tracking of the ladles in the plant to start the optimization after a period of collecting data.