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THE BADISCHE MULTIROB – SAFETY AND PERFROMANCE ARE KEY TO SUCCESSFUL STEEL MAKING*

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Abstract

Safety was always in the focus of Badische Stahlwerke, however at the same time productivity has to increase as well in order to compete in a tough world market. In 2015 BSW produced over 2.2 Mio tons with two EAFs, leading to tap-to-tap times in average of under 40 minutes. Our philosophy has always been, that our most important success factor are the people: therefore we have to improve the working conditions as much as we can. Starting in 2012 Badische developed a robot that can support this goal. The first step was to use it for temp/sample taking, but the unit had to become a multi-tasker. Only 2 years later the first automated cartridge changer was installed at a customer site in Scandinavia, in late 2015 then the next tool was implement: tool changer allows now to use also a camera to check the condition inside of the heat after tapping. More tools are designed currently and will be implemented shortly. This paper describes the current installations and experiences as future applications.

Keywords: Safety; Performance; Robot; Cost reduction.

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1 INTRODUCTION

Since 1968 Badische Stahlwerke GmbH (BSW) has been operating two 100 ton EAFs, in 2015 tap-to-tap times of under 40 minutes, with a 2-bucket charge, have been achieved. The faster paced the furnaces become the more dangerous the work environment can become. BSW has always considered its people its most important asset and the key to their success. To aim for the top level of safety is every steel maker's task: the question is how to achieve it, can we do more?
There is another aspect which has to be considered: most western societies, not only Germany, are facing the problems of an aging work force. Today the baby boomer generation is over 50 years old and soon these experts will retire. The younger generation likes to work in a clean and more automated work place. The younger generation looks to the work environment with different eyes, and it is already difficult to hire people willing to work at a melt shop.
On top of this, governmental regulations as well as union rules are starting to be enforced in much of the industrialized world. Other European countries already have laws restricting the entry to the furnace platform during operation; access doors to the furnace platform are locked between charging and tapping.

History of Robotics at Badische
Badische Stahl-Engineering (BSE) designed its first lance manipulator (LM) in 1985 for oxygen and carbon injection through the furnace door. This was a huge safety improvement for the operators as the operation was previously via a hand held lance.

Figure 1&2: Hand lancing on the left and the first LM from 1985 on the right

This was followed in 1992 by a temperature and sample manipulator for the EAF. In 2008 Badische upgraded then also their Ladle Furnaces. Since then not one accident related to these operations has been reported, however, they do have their limitations, particularly in confined spaces and the need for automated cartridge changes.

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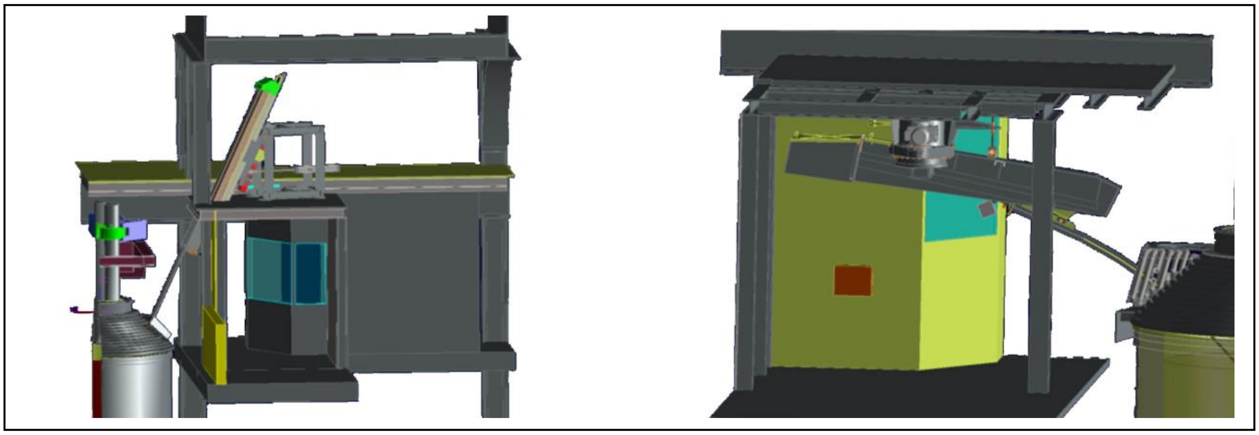

Figure 3: TSM for EAF#1 and #2 at BSE from 2008 and 2009

Based on the realities described above, BSE decided in 2010 to start evaluating the option of implementing robot technology in steel plants with the aim, of further increasing safety. The bottom line target is to get the people off the furnace platform when the EAF is in production.

Higher safety but also possible new risks

From the early conceptional phase we involved the Fraunhofer Institut (http://www.ipa.fraunhofer.de/) and our safety engineers to find a solution for a safe installation of a robot in a steel plant.

The installation of a robot at the furnace platform could potentially do a whole range of tasks such as temperature dips, slag/metal samples, door burner and oxygen injection, gunning, automatic tap-hole opening, cleaning and filling. These operations could increase safety, but new risks could also arise.

A robot can be stronger and faster than any human and, due to its flexibility, the movement logic can be different. The installation of a fence for personnel protection on the furnace platform, like in the automotive industry, was not an option because it can be a handicap if one has to escape from any danger coming from the furnace. The possible risks caused by the furnace are much higher than being hit by a moving robot, so BSE created virtual fences and areas. The robot has a redundant feedback of its position. It has a safety PLC sitting on top of the regular robot control where speed and access options to different areas can be programmed. If robot moves different to that expected, then it stops (Performance level d, DIN 13849).

The robot can move the tool up to 100 m/s, therefore a safe speed limit on the furnace platform of 1 m/s (walking speed) was implemented in Area B as shown in figure 1. In the human/robot cooperation area (Area A) the speed limit was set to 0.5 m/s.

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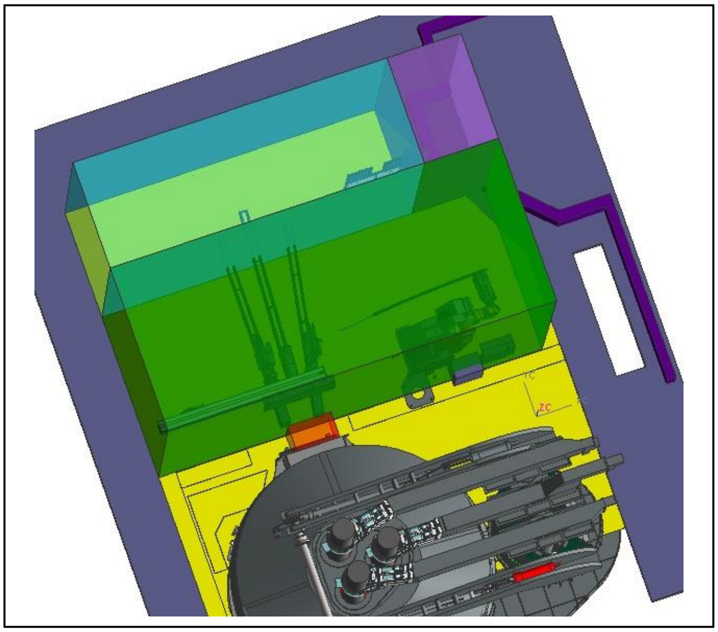

Figure 4 Safety zones at BSW EAF#2

Initial Steps

After we defined the potential tasks we decided that the first job should be the same as the regular TSM, taking samples and temperature. With over 130 installations of the TSM we had plenty of experience.

In 2010 a team from BSW and BSE visited several robot suppliers to identify what options were available and at what stage of development the robot industry was to help us. At that time robots were already used in foundries and a variety of manufacturing places and some were also used at continuous casters and in the downstream area, but no robot supplier had a steel plant-ready unit.

In December the same year Badische decided to develop its own version in cooperation with the company Kuka, a leading German robot manufacturer located in Augsburg, Bavaria. With its close proximity and also known as the premium supplier we found the ideal partner.

The size of the robot bought was a 500 kg version, probably bigger than was necessary, but BSE wanted to have more flexibility for later use (see figure 5).

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Figure 5 Kuka KR500 foundry

In February 2011 BSE received the standard version of a foundry robot.
Initially BSE had to understand the programming of such a unit and it was clear from the beginning that it needed to be simplified as it had not only to be able to work in the melt shop environment, but also must be easy to repair and program.
As mentioned we replicated the functions of the temperature and sample manipulator (TSM) which had been in use since the early 1990s. The accessible position of the TSM and a good visual exposure provided a perfect opportunity for proper implementation, tuning and maintaining.
In this pre-phase BSE designed a similar `banana` lance to that already used in the TSM as it was a proven technology and therefore easy to adapt. Also maintenance requirements were known and, in the case of an emergency, a quick exchange could be done without re-training.
We were aware of the large amount of plastic hose, shields, and covers that were used on the robot so protected it with a `silver suit`. This first test was basically a heat resistant test and ended after a few hours with a damaged robot. The suit protection was so poor that even the standard (as delivered) cables below the suit got burned by slag splashes.
This led to designing a heat shield for the robot in the region of the first 3 axes of movement. The silver suit was still used for the `complicated` axes 4 to 6. The original cable tree was replaced with one with a heat resistance up to 180°C and further protected by a metallic and fiberglass hose. This protection was acceptable, however, due to the excessive weight of the protective shielding, a forklift truck or a crane had to be used to lift the heat shield. Also the initially designed service openings were simply too small to provide good access.
The robot was mounted on the furnace floor so troubleshooting had to be performed on the floor right in front of the hot furnace. The silver suit on axis 4 to 6 still got damaged by slag splashes, and also metallic dust took its toll very quickly on this basic suit protection.

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2nd and 3rd Generation

The above constraints required a re-design. The robot was positioned on a 500 mm-high platform for convenient maintenance access to all parts. Metal heat shields were used instead of the silver suit, all heat shields could now be taken off easily by hand and there is no tool needed for dismantling. The lifetime of these protective shields turned out to be basically infinite.

A switch was implemented that enabled the operator to pull the lance out of the furnace by hand in case of a power loss or other failure. The second helper, who performs the cartridge change still had to be relatively close to the EAF door, but due to the flexible robot movement the first helper can now be more than 7 m away from the furnace door and is protected by a shield.

Figure 3 shows the design installed at EAF#2 from 2012 to 2015. After successful operation of more than 6 months it was decided to give the robot a name. Due to its versatile functionality BSE chose the name MultiROB.

The next target was to increase safety with fully automatic operation of the cartridge changer. For these capabilities the initial 500 kg robot was not necessary, but in order to use a smaller 300 kg robot BSE had to redesign the relatively heavy water cooled lance. This robot is more flexible and has more variety of movements, which negated the need for the banana shape of the previous lance design. Compressed air cooling was used to reduce weight and increase safety by eliminating the need for water entirely.

The Cartridge Rack

So far the robot was only performing the function of the TSM, but in a next step we had to develop a cartridge rack. This was an important step, since it now allowed now to run through each heat without anybody being even on the furnace floor.

Equally important was that it could fulfill following specific requirements:

- Easy maintenance
- Good accessibility for refill
- Availability to contain minimum of 40 cartridges
- Small foot print
- Positioning on a furnace platform with quick release couplings
- Enable MultiROB to mount cartridge on the lance tip without additional drives
- Minimal protection needed, no special housing

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- Capability of straightening the lance

Figure 8: Cartridge rack and MultiROB at Outokumpu Avesta

Function of the cartridge rack: The old cartridge is stripped off on one of the two V shape shear blades on top of the rack's roof. It rolls down the roof and falls into a coaster wagon for disposal. Robot accuracy is particularly important in relation to the cartridge picking operation.
The gap between the lance tip and the cartridge is only 1 mm, the lance and lance tip is ~ 4 m long and the robot arm is ~ 3 m, thus with a 7 m long tool, we have to hit a hole with a gap of 1 mm. If the lance tip is out of proper position or not at the correct angle due to thermal expansion or collisions inside the EAF, this would be impossible. Therefore, in order to properly insert the tip into a cartridge the precise position of the lance tip and the angle needs to be known.
The unit also has the capability to adjust the lance shape back to normal and can handle misalignment in the range of +/- 70 mm. This is done using openings at two swing plates. The first swing plate detects that the lance needs to be bent back to normal. The second swing plate determines if the lance tip needs automatic realignment. Only after both plates are passed, cartridges can be selected again. The gripper holding the cartridge is the only driven part at the rack. The bending is done at the cone in the upper part of the rack.
If the lance is bent beyond the above range the operator or maintenance expert is able to use a service position that moves the lance tip to a target range. After lance adjustment the system can be reactivated by pressing the start button.

Programming, Operations and Service Philosophy

The use of robots in industry is dominated by the automotive industry where they are maintained by dedicated teams of expert technicians. In a steel plant such expertise is not generally available and an ordinary electrician without special training must be able to handle everything from the crane at the scrap yard to the maintenance at the rolling

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mill. Therefore, the programming was simplified to the point that the programmer speaks `the same language` as the operator.
Due to the versatility of a robot, programming steps are similar to real life.

- Who am I?
- Where do I want to go?
- How fast would I like to get there?
- How much energy am I willing to spend to get there?
- What shall I do if I fail? What is my plan B?

The programming was modified in such a way that the robot operating interface should not be affected. The very high reliability of the robot creates the problem that the electrician may forget the troubleshooting procedures. To keep his acknowledge alive, a short web-based training via Skype is available on a frequent basis.
Due to the high flexibility of the system, the possible combination of the movements is almost infinite, therefore basic setup was limited to following:

- 3 measurement positions inside the EAF (left, center, right)
- 3 different heights (up, regular, down) (e.g. to handle different refractory status)
- 3 different parking positions
- 8 different service positions

In case the robot has to be removed for e.g. for the yearly maintenance or a furnace shell exchange, the system is designed, that there is nothing left on the furnace platform. All junction boxes are mounted on 0 m elevation, and all cables from this point to the furnace platform elevation are heat resistant.
A five day personnel training on-site during the factory acceptance test is sufficient to cover all fields. The cabinet comes on wheels and can be moved by fork lift or crane. BSW tries to avoid maintenance or trouble shooting in front of a running furnace so easy dismantling via wedges and quick couplings are provided.

Customer Installations

In August 2014 BSE installed its first robot at a customer site at Outokumpu Avesta in Sweden to measure the temperature in liquid steel with the above mentioned fully automatic cartridge exchange. The plant had to comply with the regulation that no one is allowed on the EAF platform when the furnace was under power. The fact that this plant is a stainless steel producer gave MultiROB a real test: the slag is harder than at BSW so we could see how this new lighter lance would hold up under these conditions.
In 2015 more installations followed and the first robot was put into operation at a plant in China (see figure 10).

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Figure 9&10: MultiROB installed at a plant in Sweden (L) and China (R)

Multi-Tool Functionality

To make a robot really worth the investment the MultiROB to had to have even more functions. This next step and function was a tool changer.

Several possible suppliers were evaluated for this task, but since no simple and rigid solution could be found on the market, BSE has built its own tool changer. The 3rd generation with an improved heat shield arrangement and equipped with a tool changer was installed in October 2015.

Besides reliable temperature and sample taking the robot has been performing a new function of furnace inspection with a thermal camera through the furnace door.

No pneumatic or hydraulic cylinder for clamping is needed and no limit switches indicating the tool readiness are implanted. The reason is the same as with the cylinders: the lifetime of such equipment would be too short and maintenance intense operating at or in the EAF. If there is failure, the operator needs to have the opportunity to attach the tool manually.

Figure 11: The tool changer.

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It was commissioned in conjunction with a camera tool at BSW in 2015. The right hand side with the hook on top and the two pins shows the tool changer mounted on the robot. The plate with the two holes shows the counterpart mounted on the tool.
The MultiROB is now able to change tools between temperature and sample taking and thermal camera. This camera scans the refractory status of the EAF and search for cooling panel leakages. Also a visual bath level measurement is possible (see fig 12).

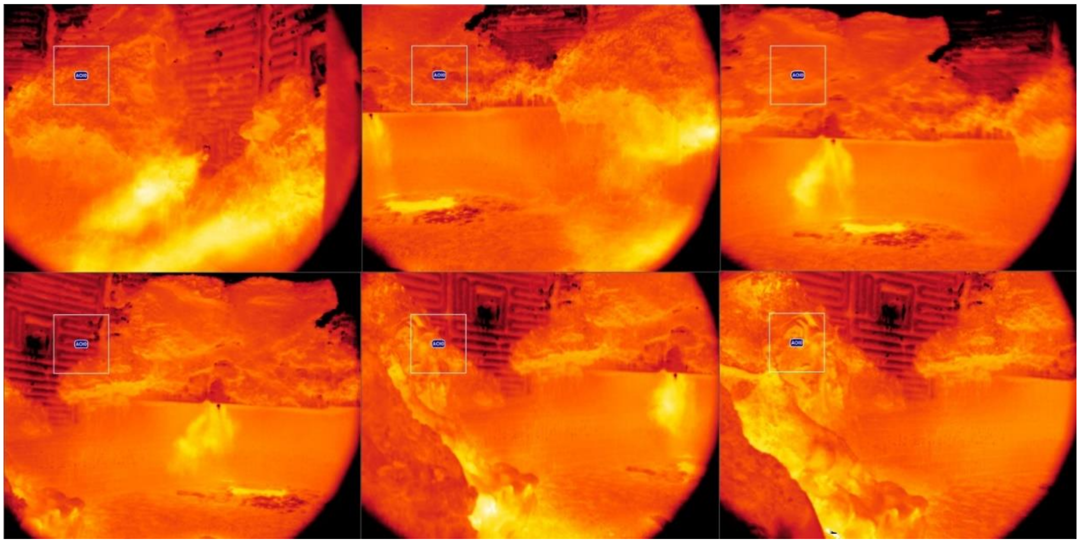

Figure 12: Furnace inspection with MultiROB and thermal camera

Performance and Conclusions

The MultiROB at BSW has been running for a total of more than 4 years. Since the upgrade to the latest version in 2015 no major failures have occurred. A robot reliability of 99.8% over the course of 24 months and a reliability of the rack of 98% has been achieved. All the target parameters for precision and lifetime have been exceeded so far and the implementation of this new safety equipment has not slowed down the steel plant.
Similar accounts have been experienced at Outokumpu Avesta. The equipment operates in a tougher environment with not only much harder stainless steel slags, more movement required but also their EAF is equipped with an electromagnetic stirrer. Even under these tough side conditions of much more movement and electromagnetic noise it turned out to be a trouble-free operation since the start up in August 2014.
The fully automated steel plant is not science fiction, and robots will play their part. Initially they will help to improve safety but increasingly performance enhancement functions will come into focus. They are highly reliable if designed correctly for the steel plant environment, are able to perform jobs in a very confined space, since they are very flexibility and their foot print is small and they will start a new understanding of maintenance-free operation.
By improving the working conditions BSE will be able to make the steel industry more attractive. The shift from standard labor to more sophisticated automation technicians has already taken place with most equipment. A robot will make life easier and might perform tasks we cannot even think of today. In the near future BSE will focus on the

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step-by-step implementation of the additional functionality for the steelmaking robots such as: Door burner, oxygen injection, gunning with remote control and automatic tap-hole opening, cleaning and filling.

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