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# LIQUIROB® – IMPROVED SAFETY AND SYSTEMATIC PROCEDURES ON THE CASTING FLOOR USING ADVANCED ROBOTICS[1]

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**Abstract**

For several years Siemens-VAI has been promoting the use of Robotics in steel plants to improve the working conditions for operating personnel. The main reason for using robotics is to improve safety of working close to liquid steel. The Siemens VAI solution for robotics in steel plants is called LiquiRob®. Several advances have been made. The first two installations on continuous casting have been running for several years, at POSCO Gwangyang, South Korea and Companhia Siderurgica Paulista, Brazil. Furthermore there is one installation at voestalpine Linz which was started up in early 2011 and one installation is under preparation. Recently the first installation on an EAF for RIVA Neuves-Maisons, France had its successful start-up and the first two installations on a LD (BOF) converter for ThyssenKrupp CSA, Brazil have also started up. At first, this paper reviews the experience with such references. It shows the progress made on several LiquiRob® functions, such as tundish powder feeding, position detection of ladles and as an additional challenge ladle oxygen lancing. For all these functions the development is completed and successful installations are in operation today. Finally the overall safety concept of a LiquiRob® plant on a continuous casting machine is discussed, the interrelationship with the casting safety norm EN 14753 is investigated and solutions to allow a safe combination of human and robot operation are demonstrated.

**Keywords:** Robotics; Safety; No man casting.

## LIQUIROB® – MELHORIA NA SEGURANÇA E PROCEDIMENTOS SISTEMATIZADOS NA PLATAFORMA DE LINGOTAMENTO UTILIZANDO ROBOTIZAÇÃO AVANÇADA

**Resumo**

Por vários anos, a Siemens-VAI tem promovido o uso da robótica nas plantas de Siderurgia objetivando a melhoraria das condições de trabalho para o pessoal de operação. A principal razão para a utilização da robótica é melhorar a segurança para trabalhar próximo do aço líquido. A solução da Siemens VAI para a robótica nas plantas de Siderurgia é chamada LiquiRob®. Vários avanços já foram feitos. As duas primeiras instalações em plantas de Lingotamento Contínuo têm funcionado por vários anos na Usina Posco Gwangyang, Coreia do Sul e na Usiminas - Cubatão, antiga Cosipa, Brasil. Além disso, há uma instalação na Voestalpine em Linz – Áustria que entrou em operação no início de 2011 e uma instalação que está em fase de preparação. Recentemente a primeira instalação em um EAF da RIVA Neuves-Maisons, na França teve o seu start-up bem sucedido e as duas primeiras instalações em Convertedores LD (BOF), para a ThyssenKrupp CSA - Brasil, também entraram em operação. Inicialmente este trabalho analisa a experiência com essas referências. Ela mostra o progresso feito em várias funções do LiquiRob® tais como, a alimentação de pó fluxante, detecção de posição de Panelas e, como um desafio adicional, lanças de oxigênio para Panela. Para todas estas funções o desenvolvimento está concluído e instalações bem-sucedidas estão hoje em operação. Finalmente, o conceito de segurança global de uma instalação LiquiRob® em uma Máquina de Lingotamento Contínuo é discutida, a sua correlação com a norma de segurança de Lingotamento - EN 14753 é investigada e soluções para permitir uma combinação segura de operação humana e com robôs são demonstradas

**Palavras-chave:** Robótica; Segurança; Lingotamento sem operador.

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## Introduction

In the past several years, the steel industry has been placing an increased emphasis on fully automatic production lines with a high degree of reliability. One part of this process has been the replacing of manual labor by single purpose manipulators. In continuous casting plants, the use of a ladle shroud manipulator is very common now, and the generation change from manual to semi-automatic manipulators is on the way. However, one main problem of the single purpose manipulator concept is that with every additional manipulator task an additional manipulator has to be installed, making the overall system unreliable and maintenance intensive. Additionally, every manipulator which can operate in an automatic mode is a potential safety risk.
Under these circumstances, Siemens VAI introduced a successful innovation concept for an automatic casting platform with the use of robots(1) in 2004. The main development goals were:

- The use of standard industrial robots, which have been developed for car industry and have entered the area of foundries, metal industry and steel plants in the last decade (Figure 1)
- A holistic concept where one robot can carry out a multitude of tasks and several robots can work together to have a fully automatic steel plant

All further development efforts can be derived from these two goals. Why are these two points so important? Standard robots offer several advantages. On one hand the cumulated sum of sold industrial robots since the 1960's was 2,2 Million units at the end of 2009 with the total worldwide stock of operational industrial robots is in the range of 1 to 1,3 million units.(2) The result of this is that basically any problem regarding safety, reliability and flexibility has been solved in one way or the other for industrial robots and has only to be transformed to meet the demands of the steel industry. The other main advantage is that there is a world-wide service structure for industrial robots available.

**Figure 1**: Robots working in a forging plant (Courtesy of KUKA Robot Group).

The other goal of a holistic concept comes from the customer demand to have only one robot family at its plants. A patchwork of different solutions would make it much more complicated to develop cost efficient safety, operation and maintenance

concepts.
The result is the LiquiRob® system which consists of a box of different modules which can be combined to solve several tasks. All of these are sturdy reliable and fit for use in a steel plant. Siemens-VAI has built with these modules applications for continuous casting, BOF steelmaking and EAF steelmaking.

## First References at a CCM, POSCO Gwangyang 2-3

After several years of development and laboratory tests,(2) the first reference at a continuous casting plant was the POSCO Gwangyang 2-3 machine.

(a) during measurement operation (b) on moving unit in home position
**Figure 2**: LiquiRob® on CCM 2-3, POSCO Gwangyang.

The LiquiRob® tasks in Gwangyang are tundish steel measurement, tundish steel sampling and powder feeding. The positive experience from this first installation is that the robot is perfectly well fitted to work in this environment. The other LiquiRob® system components like the tool changer and the robot moving unit were also working for the first 3 years without noticeable wear. Only parts of the protection cover of the robot have to be exchanged approximately once a year. The LiquiRob® carried out 21000 temperature measurements, took 9000 samples and supplied 4000 shovels of powder in the first year of operation.
There are several conclusions from POSCO Gwangyang. First, the robot is perfectly suited for the operation in a steel plant. Second, the design of the tool changer, the robot moving unit, the protection suit and several other components is reliable enough to be used in other plants. Third, the development efforts have to focus on simple, maintenance friendly solutions where the robot is the only “intelligent part”.

## Second Reference at a CCM, Usiminas Cubatão (COSIPA) CCM3

This second reference started up in April 2008, just 6 month after POSCO Gwangyang. The functions installed there are temperature measurement and steel sampling. The setup is quite similar to Gwangyang, however, no moving unit and no powder magazines have been needed. The remaining equipment is basically identically. The LiquiRob® has operated very reliably since the startup. After damage to the LiquiRob®, Usiminas immediately made an inquiry to Siemens-VAI to replace it.

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(a) during measurement operation

(b) on LOP in home position

**Figure 3**: LiquiRob® on CCM 3, Usiminas Cubatão

Siemens-VAI awarded a contract for this second LiquiRob®. During a scheduled shutdown, the LiquiRob® was reinstalled in two days and is in operation in Cubatão since August 2009.

**Third reference at an EAF in Riva Neuves maisons**

The third installation of a LiquiRob® at SAM Neuves Maisons - RIVA France, the LiquiRob® replaced an existing semi-automatic manipulator for measurements and sampling. One goal of the design of the robot equipment was to withstand the harsh conditions close to the EAF especially the high magnetic fields. Another challenge was the comparable short erection and cold test period which started on the 27th of December 2009 and ended on the 4th of January 2010 with the first heat using the LiquiRob® for measuring oxygen content and temperature in the liquid steel.

**Figure 4**: LiquiRob® during oxygen measurement operation in EAF.

The LiquiRob® showed reliable operation. Adjustments to improve arm and tip cooling as well concerning movements have been done in the commissioning phase, resulting in performing the jobs with the promised availability > 95% and cycle times less < 90 seconds from pick up of new cartridge via check of cartridge and measuring cycle until drop of used cartridge. The robot is working since this time in continuous operation.

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**Fourth Reference at a BOF in ThyssenKrupp CSA, Brazil**

The fourth installation of a LiquiRob® is at ThyssenKrupp CSA Brazil at the two BOF plants. The first heat with the LiquiRob® in operation has been in September 2010. It consists of two LiquiRob® units which take sublance probes (T, TSC and TSO probes) out of automated probe magazines and attach them to the sublance.

**Figure 5**: LiquiRob® disconnecting a probe cartridge from the sublance

The LiquiRob® recognizes defective probes and sorts them out thus avoiding time consuming measurement errors. Furthermore it is also possible to check the contact rod position so the availability of the system is guaranteed.

**Fifth Reference at a CCM in voestalpine Stahl Linz, Austria CCM 5**

The fifth installation of a LiquiRob® was on a CCM at voestalpine Stahl Linz, Austria. The commissioning of the LiquiRob® started during the writing of this paper in early 2011. It replaced an existing hydraulic temperature and sample manipulator. Since VAS has an excellent experience with a robot on the CC6, the decision to go for a robot solution was clear.
The functions of the LiquiRob® are temperature, oxygen and hydrogen measurement, steel sampling in the tundish and ladle oxygen lancing.
The applications hydrogen measurement and ladle oxygen lancing were carried out for the first time. Additionally, it is the first plant with actor and sensor free probe magazines. This effectively decreases the necessary maintenance effort and increases the availability of the overall system. Especially the oxygen lancing by a robot is a very important milestone. Already the first oxygen lance ignited automatically inside the collector nozzle. The robot can take single lances from a storage magazine of five lances. The setup will hopefully increase the successful ladle oxygen lancing operations compared to manual lancing, but this has to be proved during the commissioning phase
The main customer benefits are

- Increased operator safety.
- no more manual operations on the LOP are necessary and this with just one

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piece of equipment.

- reduced Maintenance costs
- faster cycle times

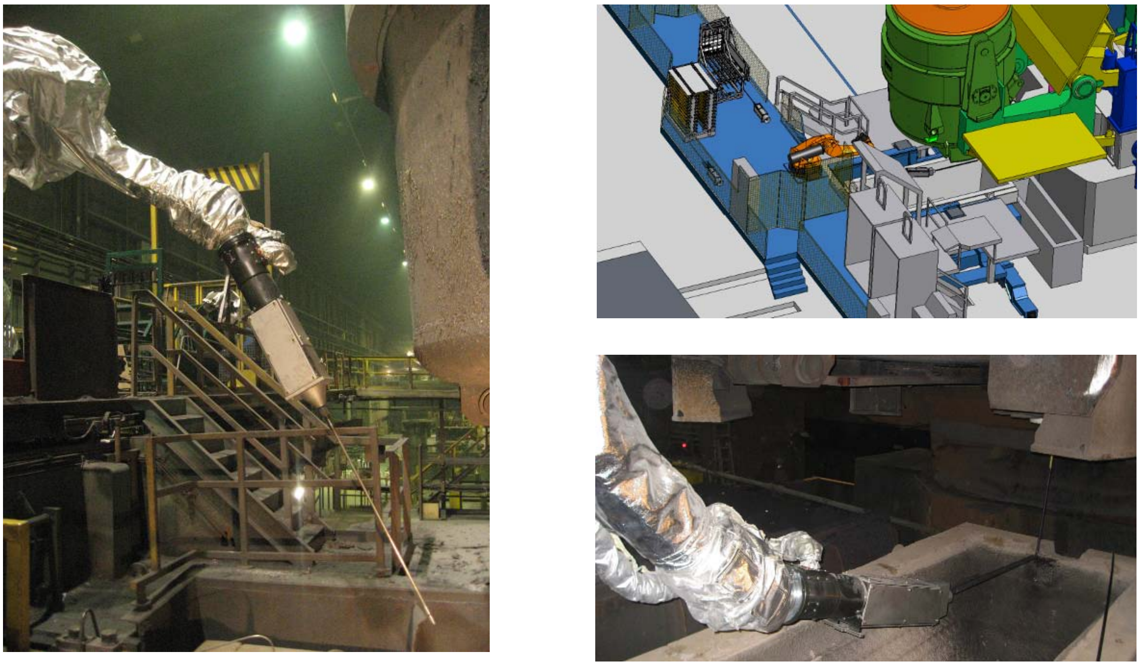

**Figure 6**: CCM5 Layout and pictures of measurement and oxygen lancing position.

**Sixth Reference at a CCM in voestalpine Stahl Linz, Austria CCM 7**

The sixth reference of a LiquiRob® is also at voestalpine Stahl Linz. The expected start-up date is September 2011.

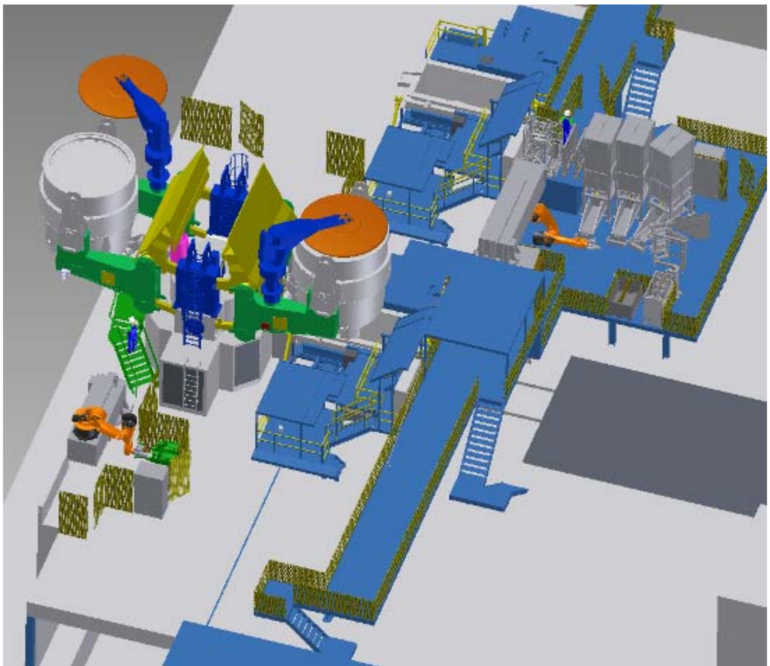

**Figure 7**: Layout of VAS CC7 with two LiquiRobs®

This is by far the most ambitious LiquiRob® installation until now. All operations for the ladle and the tundish are carried out by two robots, so that the CC7 will be the

first no-man casting floor in the world. The LiquiRob® in the ladle area connects the LSH to the slide gate. The LSH (Ladle shroud holder) is a system which combines a ladle slide gate cylinder and a shroud clamping system.(3) Additionally it connects a multicoupling for media and electric connections and unlocks a ladle safety bolt.
The LiquiRob® in the tundish area carries out all tundish measurements (Temperature, Hydrogen, Oxygen and Sampling) the tundish powder dosing the shroud handling and the ladle oxygen lancing.
One of the main challenges for such a complex plant is the synchronization of all components. Now many operations are triggered by manual input. On the CC7, most operations will run fully automatic. The tool which will allow this operation is the so-called LiquiRob® controller which is already in use in all references until now, but on the CC7 the power of this tool will for the first time really be visible.
Another challenge is the position detection of all components which are connected to the ladle. A first industrial application of this position detection package is already running in VAS CC6 in connection with a ladle shroud manipulator. The development of this system including the adaptation of the shroud manipulator needed more than three years. Since January 2010 it is successful in operation.

**Robot safety concept for casting machines**

Historically the steel industry is a very old industry which has been very dangerous. With the progress of the society in the 20th century the reduction of fatal injuries has been an important goal not only for plant operators and labor unions but also for legislation. Since the steel industry is an international industry and most legislations have been restricted to single countries, the safety standards differed very much from not only from country to country but also from company to company. One milestone was the introduction of the first version of the machinery directive of the European Union in 1989 (89/392/EWG) and the following versions 98/37/EG and 2006/42/EG which is in force since 28.12.2009. These laws basically require that any machinery which is sold in the EU complies with so-called harmonized standards. These safety standards European safety standards can be divided into basic safety standards (type A standards), safety group standards (type B standards) and machine-specific technical standards (type C standards).
Until 2007 there was no type C standard for continuous casting, so basically the plant designers and operators had to use the non-specific type A and type B standards for the plant design. This led also to a wide range of interpretation possibilities, and sometimes to the misconception that there is no safety standard and the safety installations were designed to the best knowledge of the designers and plant operators.
So a further very important milestone was the release of the European standard EN14753:2007 “Safety of Machinery – Safety requirements for machinery and equipment for continuous casting of steel”. This on the one hand helps the designer to have a guideline for the design of the plant and on the other hand puts the focus of plant operators that it is a legal requirement to comply with this standard. However, while it is a big step forward, the first edition of this standard is still not very detailed for auxiliary equipment and refers again on corresponding type-A and type-B standards.

**Example of several steps to develop a safety concept with LiquiRob®**

A big advantage of the use of industrial robots is that for robots there is a corresponding C-standard (EN ISO 10218-1:2006 and the draft prEN ISO 10218-2:2008) which gives the designer a very good guideline for the safety design of robot systems. Additionally the robot industry has also the necessary solutions to fulfill the safety requirements, while for typical manipulators the solutions to fulfill type A and B standards have to be developed on a case by case basis.
The first step in creating a safety concept for a robot in a steel plant is to do a risk analysis. A guideline how this risk analysis should be carried out is given in the EN ISO 14121. One part of this analysis is to define the possible work range of the robot including its tools. This is part of the determination of the machine limits. A 3D-layout of the plant is essential for this task.

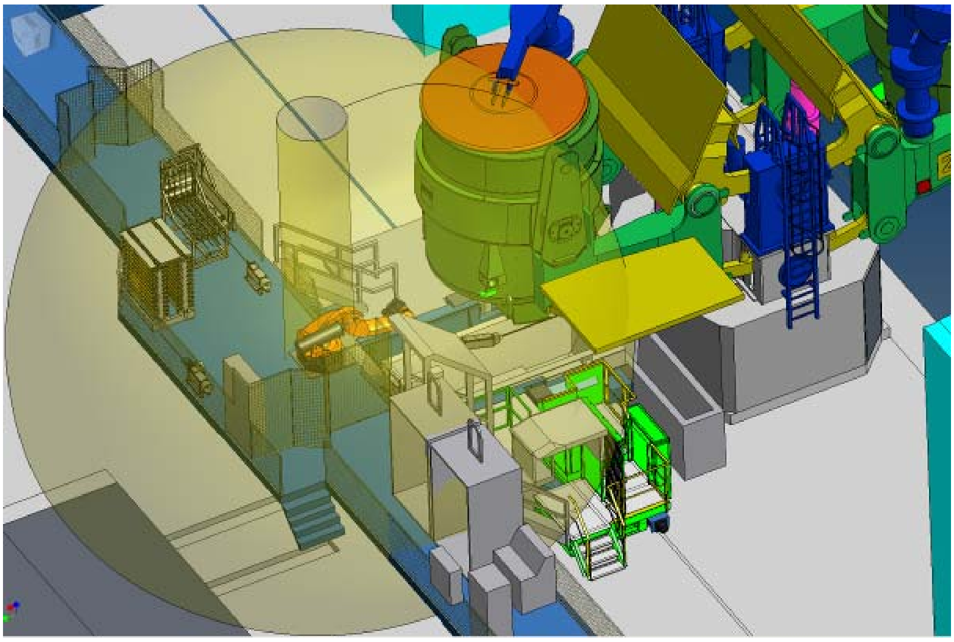

**Figure 7**: Working range of a robot on an LOP depicted as a yellow sphere

Usually the possible working space is larger than one would expect from the first view. A typical example is shown in Figure 7.
When the limits of the machine have been defined, the next step is the hazard identification and the risk estimation. The most obvious hazard for all automatically moving machinery is the impact on persons and connected crushing, shearing or stabbing of these persons. There are of course a multitude of other hazards, but this hazard during normal operation will be used as an example for the procedure in the following steps.
When all hazards have been identified and the risks have been estimated, the risk analysis is finished and the next step is the risk evaluation. For our example, the risk of impact on humans, the risk evaluation gives usually a high risk where measures have to be taken to reduce the risk. The first measure is to reduce the risk is to reduce the working range of the robot.  Typically the robot design allows adjustable mechanical movement limiters for the first three robot axis. With this, the working range can be reduced drastically. During the conception of these limits, it is important to simulate the robot movements to check if the necessary movements are still

possible with the chosen limit configuration. The next step is to design the safeguard layout i.e. where the fences and doors are placed. The fences usually prevent only that persons cannot enter the hazard area and are not for reducing the working range of the robot. However, if necessary there are also fences available which can withstand the impact of a robot at full speed. The next step is to design the safety control for the doors, entry requests etc. according to ISO 13849. Again the choice of a standard robot helps the designer, because the choice of control performance level is already described in the ISO 101218 and the necessary safety functions are already included in the robot control.
For some layouts, the mechanical limitation of the movement and the installation of fences are not enough. So, one further possibility is to extend the robot control by a safety related movement restriction. This is again a very flexible method to define areas where the robot can work and where not, which can be switched according to the operation cycle of the plant. For robots supplied by the company KUKA, this software is called Safe-operation, where all safety related hardware and hardware test cycles according to ISO 13849 are already included. Again, the simulation of the robot movement is an essential part of the design process of the movement restriction.
With these three measures, it is usually possible to reduce the risk associated with mechanical impact of automatically moving parts with humans to an adequate level. There are several other hazards related with the installation of manipulators in steel plants, which have to be included in the risk assessment and risk reduction process.
So what is the interrelationship with the caster standard EN 14753? The overall process of risk assessment and risk reduction is demanded by the EN 14753 but for the detailed process steps it is referred to the other norms which describe this process in detail. The caster safety standard is not very detailed for what solutions to use for the corresponding risk reduction. For example, there is no detailed explanation about ladle opening or other dangerous procedures, another example is that for shroud manipulators the control system is required to have a specific performance level, but how manual shroud manipulators are designed still has to be a result of the risk assessment. It is very probable that future editions of the caster safety standard will introduce more specific requirements for machinery and operation procedures. This will also include the use of manipulators or robots for certain operations, where a complete robot solution can again reduce the safety requirements on other parts of the machinery because no-one has to enter the hazardous areas.

## Conclusions and Outlook

Siemens VAI has successfully installed several robot applications for caster, electric arc furnaces and basic oxygen furnaces. The development during the last years focused on making the systems as maintenance free as possible while maintaining the fully automatic operation approach.

Safety standards like the EN 14753 and the ISO 10218 have to be a part of the design process for all type of automatically moving equipment, where robots have the big advantage of the availability of corresponding solutions.
The already developed functions can be used to custom design a LiquiRob® system for a lot of demands. The future will bring us on the one hand more robot installations in steel plants with increasing complexity, while on the other hand the requirements in the standards will become more and more detailed.

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