DANIELI CONVERTER TECHNOLOGY NEW FULL-LINER COMPETENCE IN CONVERTER STEELMAKING[1]

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Abstract

Danieli established a new product line called Danieli Linz Technology (Austria) where proven Austrian converter specialists take care of converter design, engineering as well as process. Moreover Danieli R&D researchers based at the Danieli Headquarters in Italy support several developments such as converter suspension system, converter tilting drive, etc. Danieli high level workshop capabilities mainly based in Italy and Thailand allow 100% in-house manufacturing of the converter and all main related items, this leads to following advantages: maximized design flexibilities due to a close relation between engineering and fabrication, shortest project durations and optimized manufacturing monitoring.Together with Danieli Corus (Netherlands) having years of experience and a high number of references for converter process packages such as Sublance, Offgas analyzer, Bottom Stirring, Slag Detection and L2 Automation (SDM model) as well as their own technology for Hot Metal Desulfurization (with more than 35 references) full competence in converter steelmaking is given.Thanks to the synergy of several other specialized Danieli product lines such as Danieli Engineering, Danieli Construction, Danieli Centro Met for Secondary Metallurgy, Cranes and Environmental Technology, DANIELI is able to provide converter shops and equipment, either as single units or on a turnkey basis.

Key words: Primary metallurgy; Converter; Desulfurization; Steelmaking.

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1 INTRODUCTION

In 2011 Danieli founded a new product line for converter equipment as well as complete converter plants called Danieli Linz Technology (Austria) directly in Linz, which is the cradle of converter steelmaking particularly the LD-steelmaking process. The technicians in this office are experts in converter equipment for all core equipment, offgas system as well as auxiliaries. Not to forget, that Danieli Corus is already established in the converter business for several years. They are absolute experts for process control and cover the metallurgical part of the process.

Particularly LD Steelmaking is a quick process which demands an appropriate process control. Over the last decades, many improvements have been made in this area, such as the use of a Sublance, Waste Gas Analysis and ASCON Slag Control. All of these tools depend on a solid, well–tuned process model to be successful.

The Automatic Steelmaking System developed by Danieli Corus integrates all available tools and combines them within the Static–Dynamic process model for BOF Steelmaking. This model was first developed at the IJmuiden steel plant and further improved during implementation in other plants world-wide. It has been consistently successful with high hitting rates and substantially reduced tap–to–tap times.

Hence, together with the enormous know-how and experience of the Danieli group the missing link in the primary steelmaking process is founded and Danieli becomes a full-line supplier of metallurgical plants. This includes the classical LD-converter for the carbon-steel production as well as AOD or CLU converters for stainless steel production.

2 CONVERTER DESIGN

Still today the steelmaking converter is one of the most important equipment for producing high quality steel worldwide. From the metallurgical point of view the converter has to provide a certain reaction volume as well as bath depth and surface for the steelmaking process. In order to optimize the steelmaking process the reaction volume should be as much as possible with an ideal value for the specific volume (= ratio of inner volume to mass of liquid steel) of 1.0 m^3/t.

However, for a new steelplant this value might be possible to gain but mostly there are some restrictions which reduce the ratio to 0.8 m^3/t or even less. Particularly in the revamping business this is an issue. So, the issue is to maximize the converter volume for the specific application.

Due to the fact that lining has to have a certain thickness in order to minimize the relining sequences the vessel shell has to be increased as much as possible.

The vessel shell is the structure which acts like an enclosure of the lining and has enough stiffness to keep the complete weight in place as well as is capable to turn the converter during the steelmaking process by 360°.

3 VESSEL SHELL

The vessel shape itself is mostly driven by maximizing the reaction volume as well as e.g. already existing converters. However, a typical vessel shell has a top cone, a barrel section and a bottom cone, a dished end and a flat lip-ring on top. Knuckle sections are not necessary by experience but might be applied for other reasons. In order to minimize the relining time the converter can be equipped with a detachable bottom.

During the steelmaking process the vessel shell is exposed to extreme conditions. The shell has to carry the huge mechanical load of the weight, the tilting torques as well as dynamic loads from the process. Additionally the shell is exposed to elevated temperature up to 500°C or even above. During tapping the some parts of the vessel shell is exposed to heat radiation from the liquid steel in the ladle. In case of slopping direct contact with liquid steel or slag is possible as well. In case of too less lining inside the converter overheating (hot spot) can appear. In the worst case this can even end up in a burn through the vessel shell was happens most probably in the area of the slag-crossing.
Hence, the material selection of the vessel shell is important and has to be selected carefully in order to serve the above mentioned requirements as much as possible.
Regenerative firing Air & Fuel allows combined preheating of air and gas (fuel) and could be interesting whenever the low heating value of the fuel is below 1,000 kcal/Nm3; however, great care shall be taken to solve the problem of unburnt fuel discharging to the atmosphere at every burner shut off cycle, which, due to regenerators' volume, could easily reach 3% of the total flow.

4 MATERIAL SELECTIONS

Based on experience the most common material used is a fine grain size unalloyed pressure vessel material like ASTM 516 Gr.60, P275NH, P355NH or similar. Such material is of middle strength which comes along with high ductility in order to avoid progressive crack-growth in case of serious damage but enough strength to fulfil the requirements of a certain safety factor compared to the allowable stress level. Such material can be relatively easy to be repaired by welding.
However, due to the fact that the life time of the refractory has been increased over the years (e.g. by using Mg-C-bricks, etc.) and extended as much as possible (e.g. by slag-splashing or extended gunning) the temperature of the vessel shell under normal operation condition is increasing as well. This comes along with and increased tendency of the material to creep over the years of operation. Finally the vessel shell becomes bigger and gets closer to the trunnion ring which reduces the natural cooling effect and increases the temperature and consequently to creep effect progressively. Usually this limits the life time of the vessel shell either when the vessel shell get too high temperature or in worst case when the vessel shell touches the trunnion ring. Consequently for the vessel shell a higher creep resistance of the material has to be considered. Typical material used is P355GH, A 204 Gr.60, 16Mo3 or higher grades like 13CrMo44, A 387 Gr.11. Some suppliers even ask for Cr-Mo-alloyed steel grades like A387 Gr.22 or 10CrMo9-10. But these grade very difficult to weld and for the Cr-Mo-alloyed steel grades even post-weld-heat-treatment (PWHT) has to be applied which is very difficult to maintain in case of a weld repair in situ.
Figure 1 shows a comparison of the creep resistance in terms of creep rupture limit for a temperature of 500°C for 4 different DIN EN Materials on a logarithmic scale. For a stress level of e.g. 100 MPa the material P355GH has a creep rupture limit of approx. 3000 h, 16 Mo3 approx. 100000 h and 13CrMo4-4 and 10CrMo9-10 of approx. 400000h. This means there is a factor of approx.33 between the life time from P355GH to 16Mo3 but only a factor of approx. 4 from 16 Mo3 to the Cr-Mo-material. Due to these facts Danieli prefers to use 16Mo3 in case when creep is to be considered. The disadvantages of the Cr-Mo-material in terms of welding are too negative compared to the aim in creep life-time.

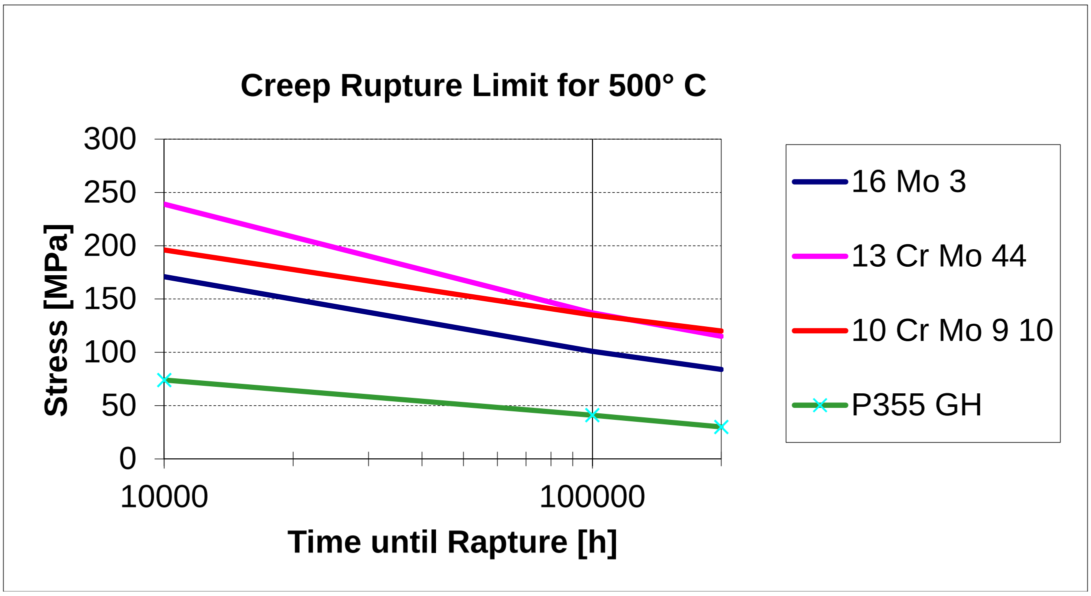

Figure 1. Comparison of the creep rupture time of different materials (typical for 300 t converter).

5 SUSPENSION SYSTEMS

A very important role in terms of converter vessel life time plays the suspension system. When material is exposed to high stresses and creep effect any additional stress has to be avoided as much as possible. In order fulfill this request the suspension system has to be as flexible as possible and as stiff as necessary.
Different suspension systems have been developed and are in operation worldwide like:

- Bracket suspension system: (compensation of thermal expansion by optimized angle of the wedges).
- Disk suspension system: Isostatic system. The converter is supported on two large disks and a link achieves and stabilizes tilting the vessel.
- Link Suspension System: Isostatic system: The converter is supported in five links and a stabilizer.
- Lamella type suspension system: The converter is supported by 8 elements underneath the trunnion ring. Each element consist of 2 thin high strength steel plates which acting like spring elements. Very flexible for radial deformation and stiff in longitudinal as well as circumferential direction. The horizontal forces in 90° position is kept by horizontal elements.

Based on the above mentioned facts Danieli developed a new suspension system. This is based on tie-rods which are arranged on 4 locations around the vessel shell. Each location incorporates 4 vertical tie-rods which are flexible for radial deformation and stiff in longitudinal as well as circumferential direction. Additionally 2 horizontal supports are arranged underneath the trunnion pins in order to take most load of the converter in 90° tilted position (see Figure 2).
This suspension system is introduced and realized on the first application of a Danieli converter system at ArcelorMittal Poland for a 350 t converter. The startup is supposed to be in April 2014.

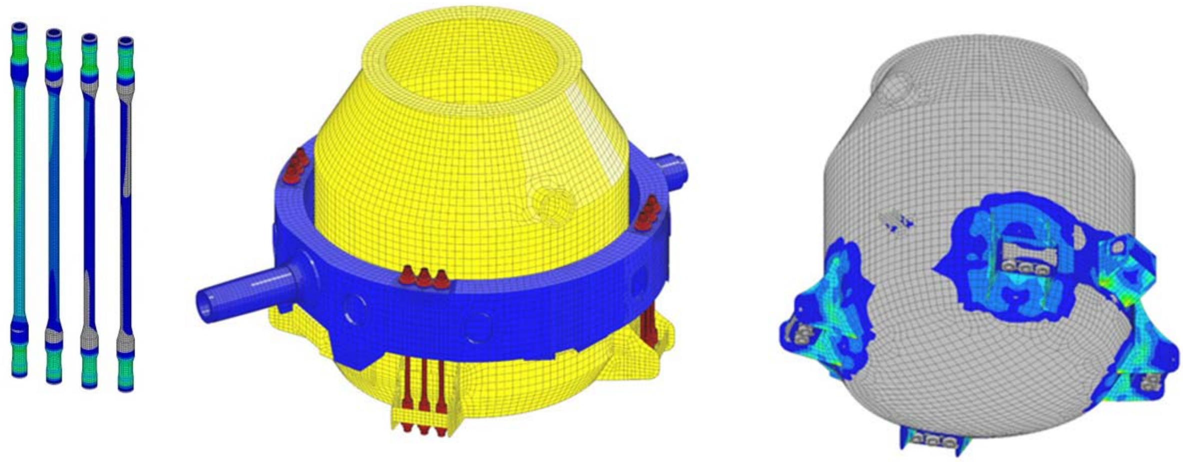

Figure 2. Calculation of suspension elements (tie rods) as well as welded-on elements.

However, Danieli develops an alternative suspension system. This is based on the lamella type vertical elements and has a special type of horizontal element which compensates the thermal expansion by elastic deformation. The patent of this system is already filed under the number MI2013A000199. An adopted horizontal element will be already installed on the 350 t converter for AM Poland (Figure 3).

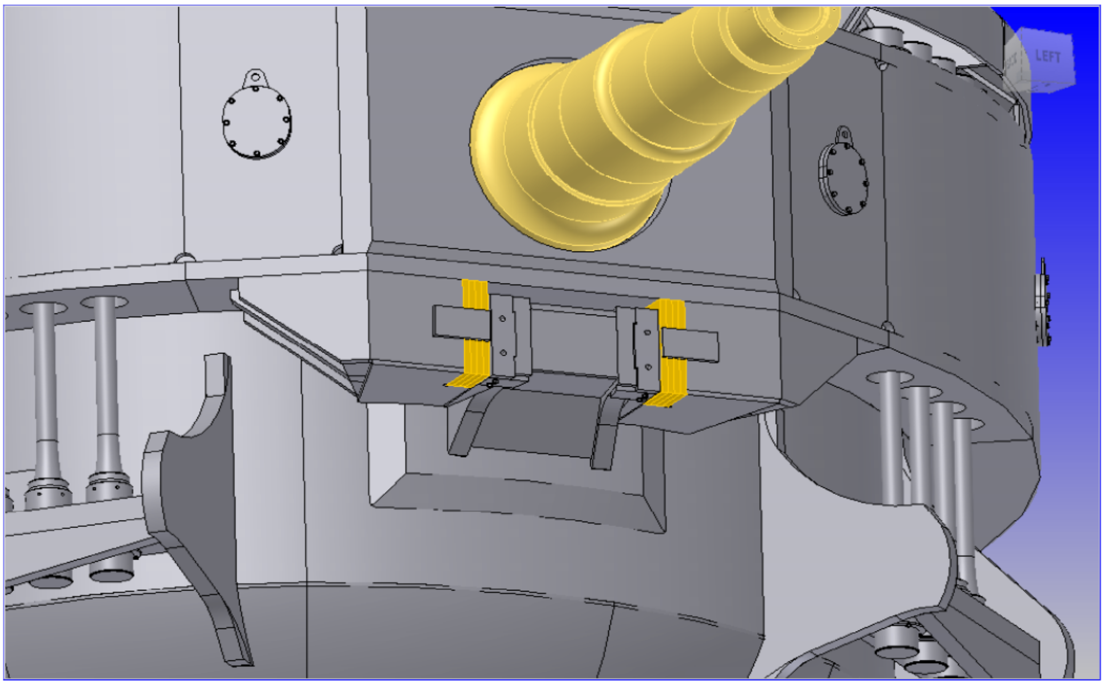

Figure 3. Compensation of thermal expansion by introduction of an elastic element package (lamella).

6 PROJECT REALIZATION AND FULL QUALITY CONTROL

An enormous advantage of Danieli is that the manufacturing of the core equipment of a converter plant can be done in-house like:

- Converter vessel shell
- Trunnion ring
- Suspension system
- Converter tilting drive

- Oxygen lance system
- etc.

Danieli comprises of several high quality production center located in Europe, Far East and China with highly qualified.

Figure 4. Danieli production centers worldwide.

Particularly for the vessel shell and trunnion ring this is of major advantage. These equipments are most critical and have to be manufactured under special care. According to experience as well as recommendation of AISE #32 the engineering, manufacturing, site assembly, etc. of the vessel shell as well as trunnion ring should be carried out according to pressure vessel code and rules.

Danieli is in a position to fully apply this recommendation via the large workshop in Thailand. Figure 5 shows some applications of manufacturing of large vessel shell within Danieli Thailand.

Figure 5. Examples of large vessel shells manufactured within Danieli Thailand.

This workshop is certified according to ISO 9001:208, ISO 14000, ISO 18000 and particularly the boiler and pressure vessel division is certified according to ASME boiler and pressure vessel code (U2 and U for production of pressure vessels as well on site, PP for production of pressure piping and S for power boilers), certified by the national board (NB) to manufacture boiler and pressure vessels and apply NB-mark and R-symbol (see Figure 6). So, it can be guaranteed that all requirements are fulfilled and under full control of Danieli.

Figure 6. ASME Certificates for Danieli Boiler and Pressure Workshop in Thailand.

This comes along with certain advantages like, minimizing of delivery time by incorporating upcoming projects already in the schedule of the workshop. Optimization of manufacturing in terms of engineering adopted to the capabilities of the workshop. This gains in minimizing the number of welding seams, minimize welding sizes in order to reduce residual stress. All manufacturing steps can be done in-house like pressing of bottom dish end or knuckle sections, stress reliving of complete trunnion ring, local stress relieving, developing of special welding procedures (WPS, WPQR and PQR) together with the Danieli welding engineers and so on. All NDT and NDE is applied in-house with qualified personnel (Level II and Level III). The quality control plan (QCP) is issued by the engineering department and directly implemented in the manufacturing process.
Keeping in mind, that manufacturing as well as pre-assembly and erection on site is done by Danieli, the preparation for site can be optimized in order to increase the quality and gain erection time.
The complete supply chain is in one hand and under full quality control of the Danieli quality control system.
With this workshop it is possible to provide additional services like keeping material or spare parts on stock for emergency cases like burn through or other unforeseeable events in order to assist steel producer in such situations.

7 CONVERTER TILTING DRIVE SYSTEM

The tilting drive of a converter has special requirements. The converter tilting torques are relatively large and varying during tilting from one side to the other. However, the most of the time the converter is not turning at all and the tilting drives act just as a big brake to the system. This comes along that the drive is split into the bull gear and primary gears varying from 1 to 6 numbers of primary gear per drive system. The modern ones have 2 or 4 primary gear and motors. Additionally in case of power failure the drive has to be operated as well in order to prevent the liquid steel from freezing in the converter. This is realized by 1 or 2 additional pneumatic motors on the drive. Due to the fact that Danieli has a lot of experience in design of large gears (from rolling technology) a suitable titling drive is developed as well. The tilting drive is “riding” on the trunnion ring axes in order to follow the elastic and dynamic deformation of the trunnion ring without creation of any additional load. The suspension system which is acting as a torque support just introduces vertical loads in the foundation. A large horizontal interconnection shaft acts like a spring and minimizes any impact loads to the teeth of the large wheel in case of shock loads or shaking of the converter during steelmaking process. The manufacturing of the drive is applied in the head-quarter of Danieli in Buttrio (Italy) and is as well under full quality control of the Danieli quality system.

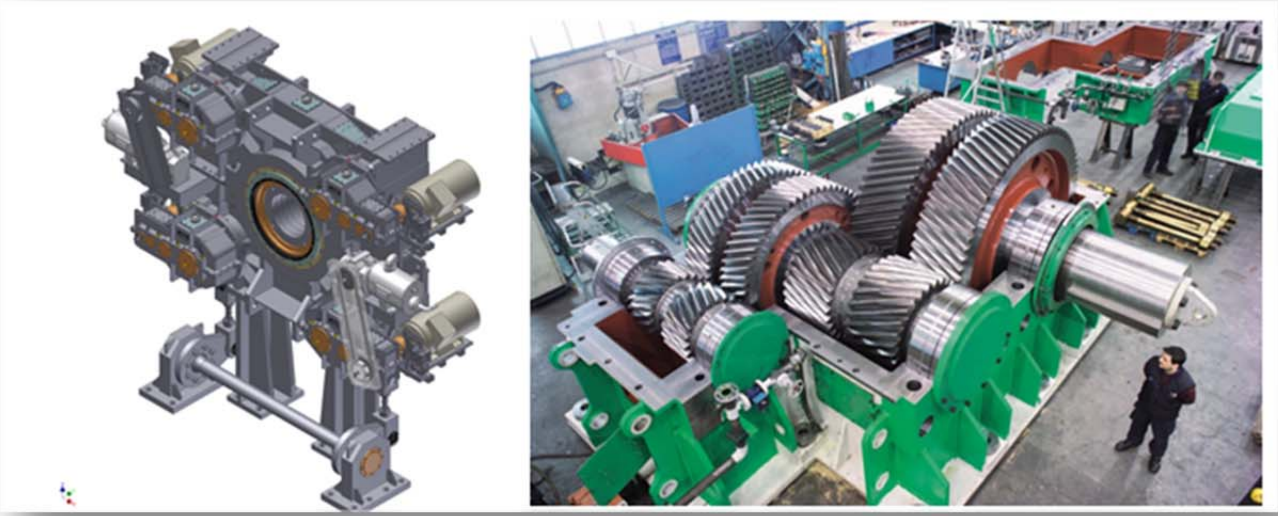

Figure 7. Design of Danieli Converter Tilting Drive (right), Example of manufacturing of drive system by Danieli for rolling mill equipment (left).

8 OXYGEN LANCE SYSTEM

The design of the oxygen lance is based on state of the art design. The design of the lance lifting device is based on the long time experience of Danieli in crane design for steelmaking plants. However, for emergency cases the lance lifting device is equipped with an emergency drive as well. The design and application of the piping and valve station for oxygen and water supply is based on the long time experience of Danieli in the field of steelmaking (see Figure 8). The application of the calculation of the water and / gas flow in the lance tip is analyzed as well using professional fluid dynamic software (see also Figure 8).

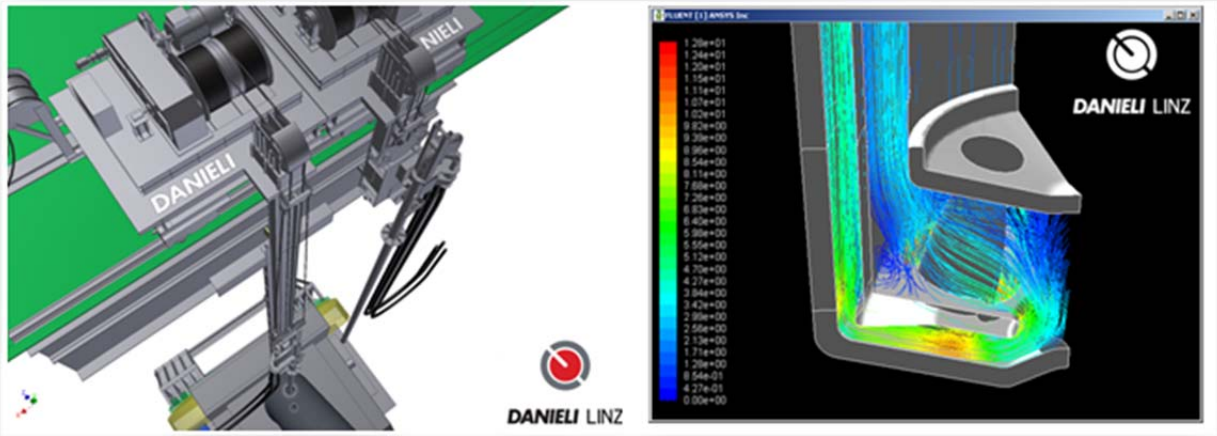

Figure 8: General arrangement of the Danieli Lance design (left) and 3/D-fluid dynamic analysis of the waterflow in the lance tip (right).

9 FROM PROCESS CONTROL TO AUTOMATIC STEELMAKING

Danieli is not only already in a position to provide a full process control system for the LD-process but additionally an intelligent control system for automatic steelmaking process control can be provided developed by the Danieli Corus group.
The Danieli Corus process control system consists of a set of hardware and software components that can be implemented individually or combined. After the initial installation, a system can be upgraded with additional modules.
A comprehensive process model is at the core of the system. The system integrates operation of and exchange of information with plant systems varying from raw material ordering all the way up to the e.g. the plant’s ERP and MES systems. With the Danieli Corus Process Control System, Basic Oxygen Converters can be operated in full computer mode based on calculations and recipes, but the system also accepts overruling by the operator.

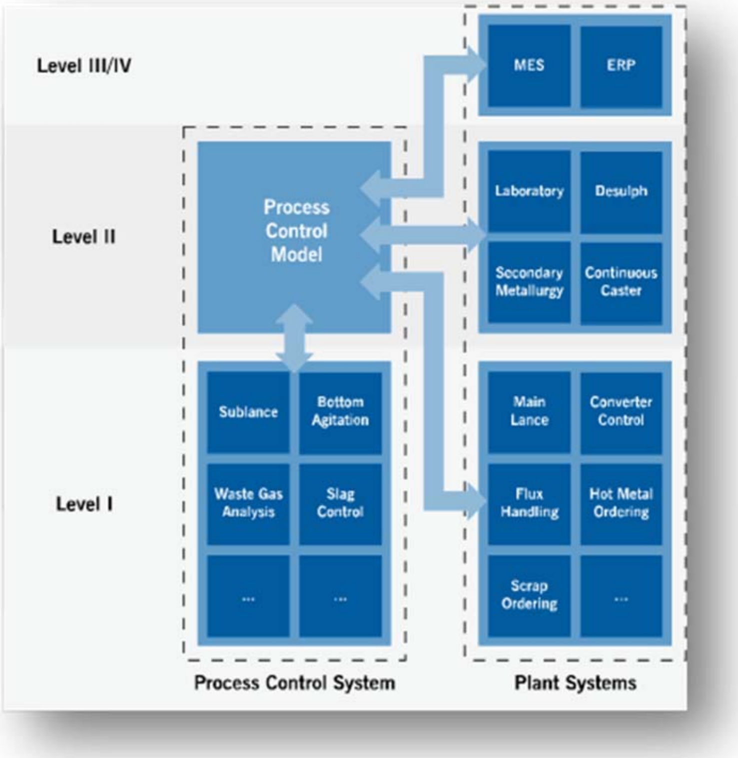

Figure 9: Danieli Corus process control system.

Over the decades, the system has been implemented at numerous steel plants. The hardware and the process model have proven their flexibility throughout all of these implementations. The system can be fine–tuned to any plant and optimized to follow existing operational procedures.

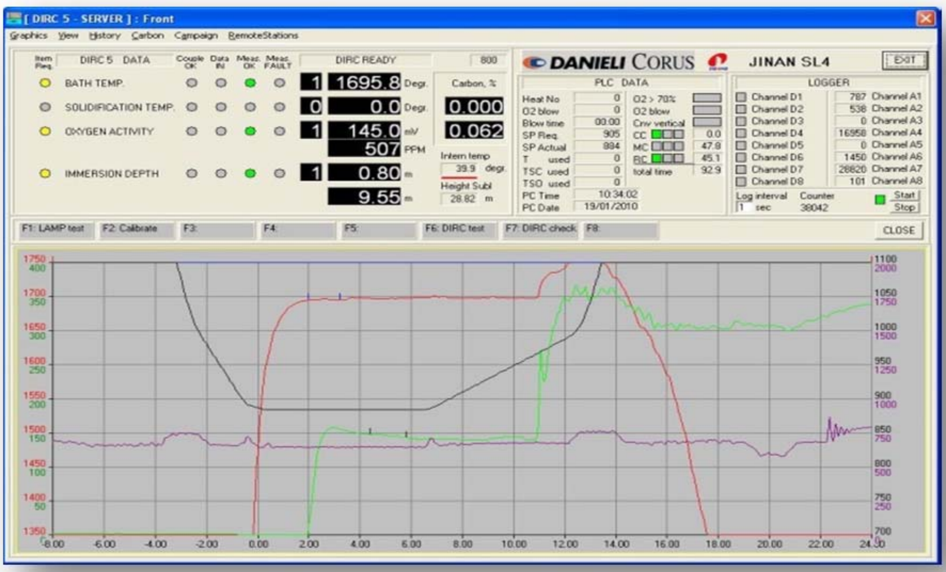

Figure 10: Typical operating system.

Hit rates of the system are illustrated in the diagrams below. The lighter blue areas indicate allowing for additional processing during the blow (cooling and carburizing respectively), the red areas indicate heats outside of specification. Table 1 indicates how the system's performance translates into value.

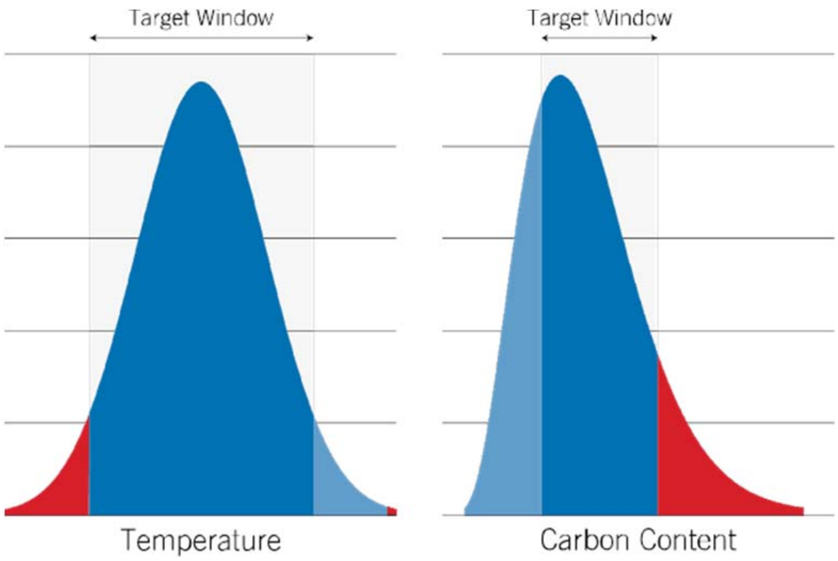

Figure 11: System hit rates.

Table 1: System performance translated into values

Tap–to–tap time	Reduced by 8 min. per heat
Hot metal consumption	Reduced by 10 kg/ton
Scrap consumption	Increased by 10 kg/ton
Oxygen consumption	Reduced by 1.0 Nm^3/ton
Aluminium consumption	Reduced by 24 kg/heat
Fe–Mn consumption	Reduced by 60 kg/heat
Energy savings	Equivalent to 20°C
Refractory wear	Reduced by 20%
Ergonomics	Better working conditions

10 SUBLANCE

The Sublance automatically takes the selected probe from a conditioned storage chamber and after moving over the converter, is lowered into the steel bath through the entrance port on top of the hood. Measurement data is fed to the process model straight away and the Sublance is retracted. The probe is removed automatically and deposited in a collection chamber on the converter floor, making a sample available to the operator within seconds.

11 WASTE GAS ANALYSIS

For additional on–line input, a Waste Gas Analysis system can be installed. This system is based on mass spectrometry, measuring the levels of carbon monoxide, carbon dioxide, oxygen, hydrogen, nitrogen, water and argon in the waste gas. This provides valuable information on the decarburization rate, the oxygen flow from the vessel and hence the oxygen content in the slag.

The data provided by the Waste Gas Analysis system is used to generate information with respect to the carbon content of the steel bath. Also, it will help update decision support information for oxygen blowing.
Since the system provides online information on converter off–gas composition, it is essential in monitoring the risk of explosions. Whenever gas composition analysis indicates serious risk of explosions, the operator will be alarmed or the system will interrupt the blowing process directly.

12 ADVANCED SLAG CONTROL (ASCON)

In converter steelmaking, dry slag leads to increased erosion of the vessel lining. Foamy slag practice, however, induces a risk of slopping. Both mechanisms are detrimental for the lining life and the availability of the converter. The slag control module offers optimized slag control through closed–loop input into the automated oxygen lance control and bottom agitation system. This process module offers automated oxygen lance height control for an optimum balance between slag foaming and process performance without slopping. The system is based on a number of measurement modules based on techniques such as ultrasonic, acoustic, etc. for online, real–time slag monitoring and control.

13 BOTTOM AGITATION

The Bottom Agitation Process offers a significant increase in oxygen blowing efficiency. It is applied to enhance the reaction between slag and liquid steel and to lower the oxygen content. Nitrogen or Argon is introduced at the bottom of the converter through special nozzles, agitating the steel bath.
The system consists of a pressure reducing system and a flow control system, capable of controlling the flow for each individual line. This achieves the desired rate of agitation and prevents damage and clogging. Flow control is split over two parallel banks. One has a fixed flow controller which is always in operation for safety reasons; the second has an adjustable flow controller, which will be switched on and off depending on the desired steel grade or process moment.
Bottom Agitation allows the steel maker to produce low end–point carbon contents without excessive yield and refractory losses. There will be an increase in yield of alloying, Manganese content in steel bath and de–oxidization materials. Slag will contain reduced amounts of ferrous elements. Compared to top blowing only, a better control of end–point nitrogen is achieved.
A unique feature of the Danieli design is that the nozzles can be drilled, allowing for tuyere replacement.

14 AUTOMATIC STEELMAKING CONCEPTS

BOF Process Control and BOF Process Automation have now reached such levels of sophistication, that it has become possible to fully automate the BOF process from charge to tap. Some aspects, however, may be more attractive to control semi–automatically with the information provided by a decision support system. This option is becoming increasingly attractive now that critical parameters with respect to liquid steel quality can be measured on-line that in the past could only be measured by taking a sample and waiting for lab analysis.

15 SAFE TAPPING®

A great benefit for the operator in the converter control room in his decision making whether to start tapping the heat or not is the addition of a decision support system. Rather than showing the measured data on the operator screen and let the operator interpret the data, process conditions are presented through a newly developed concept called Safe Tapping®. Safe Tapping® is a graphical information tool that informs the operator through a multi–color graph whether or not it is safe to start tapping the heat. After each measurement, a marker will be shown on the Safe Tapping® operator screen.
The Safe Tapping® decision support system was built for phosphorous measurement, but can be customized based on operator requirements to include any set of process parameters (such as carbon content and bath temperature windows) that are regarded essential for tapping the liquid steel. This gives the operator full control of the BOF process at high levels of confidence.
The Safe Tapping® concept was developed with the solid knowledge base that was accumulated during more than 40 years of process control in BOF steelmaking.

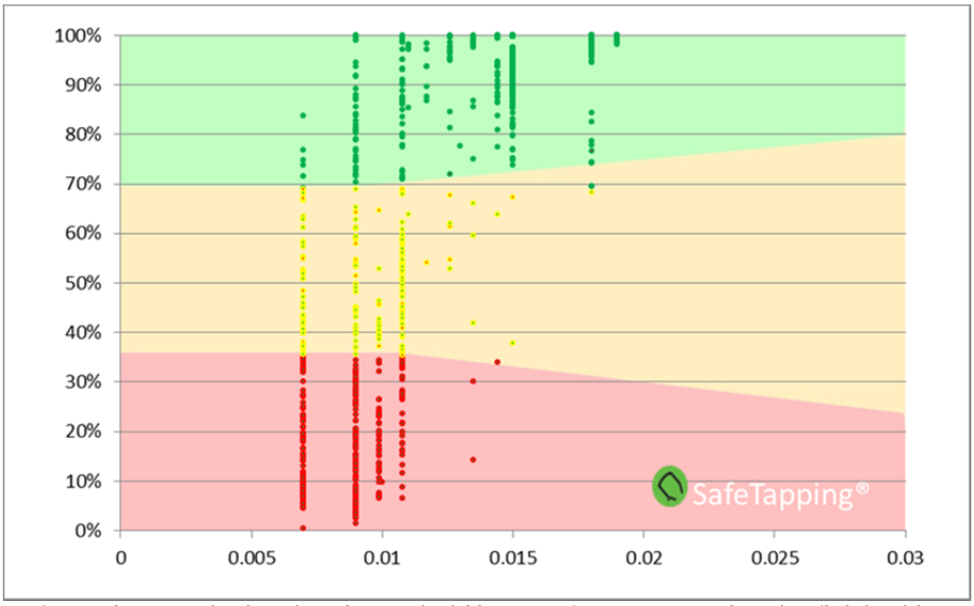

Figure 12. Information graph showing the probability to safely start tapping the finished heat and remaining under the maximum allowed Phosphorous level.

16 OPERATING THE CONVERTER IN FULL COMPUTER MODE

Modern BOF Process Control Systems have reached a level of sophistication allowing for fully computerized operation. After the hot metal and scrap have been charged into the converter (in automatic mode), the operator can start the heat with one click of a mouse button. Oxygen lance control, converter material additions systems and all process control equipment can work together in computer mode for the entire heat, until it is ready for tapping with no further human intervention required.
This is achieved by the Static–Dynamic Process Model for BOF Steelmaking. This proprietary model has been improved constantly for over 30 years now and can be fine–tuned to any oxygen steelmaking plant in the world. The model is essential in consistently achieving heats within the predetermined window for temperature and carbon content using a high level of plant automation. With this level of automation,

energy consumption, tap–to–tap times and additives consumption are further reduced.
More than 25 Static–Dynamic Process Control systems capable of running multiple oxygen steelmaking converters in full automatic mode have been installed so far. To complete the capabilities of these systems, a substantial number of related tools has proven its value in operation, such as more than 100 sublance systems.

17 ENVIRONMENTAL TECHNOLOGY

In cooperation with GEA Bischoff (Germany), Danieli has also full capabilities to handle the primary off-gases coming from the converter. GEA Bischoff has equipped more than 200 converter lines with wet (annular gap scrubber) and dry (Electrostatic precipitator) systems to fulfill highest environmental standards.
Furthermore Danieli cooperates with Oschatz (Germany) as preferred sub supplier for primary cooling stack systems, what gives additional convenience with respect to safe and reliable operation and maximized energy recovery via high sophisticated steam production.
Regarding secondary fume emissions Danieli Environment with more than 150 references for bag filter systems, provides sophisticated solutions tailor made to process and customer needs.

Figure 13. General combined know how for eco-friendly steelmaking.

18 SUMMARY

The new founded product line for converter equipment called DANIELI LINZ TECHNOLOGY (AUSTRIA) directly based in Linz Austria completes the products of Danieli to become a full line supplier for metallurgical plants.
The Danieli team in Linz has already years of experience in converter steelmaking. Together with the enormous know how in metallurgical plant building of Danieli the missing link is incorporated in the portfolio of Danieli.
This paper describes the basis of converter steelmaking and shows references of analogous application.
In particular the connection with Danieli Corus gives the opportunity to offer a complete technology setup for converter steelmaking including process control as well.
Another opportunity of Danieli is the complete integration of the production within Danieli. Hence, all core components are developed, engineered and manufactured within Danieli. This comes along with a full quality control including production, transport as well as erection and commissioning. This is unique in the market and is an opportunity for the costumer.