CONVERTER DESIGN IMPROVEMENTS AND UPGRADES FOR LONGEST POSSIBLE BOF LIFE TIME*

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Abstract

In 2011 Danieli Linz has been founded and entered as newcomer the Converter Steelmaking market. Since this time 5 BOF References (from 80t up to 350t capacity) are in operation, a 300t BOF is currently in manufacturing status and another 180t BOF is in engineering phases. In July 2018 Danieli Linz Technology was fully integrated into the well-known Danieli Corus group, located in Ijmuiden (Netherlands). This new set-up creates excellent opportunities to use synergies and combine know how from both disciplines, iron- and steelmaking to further develop technologies and products in these fields. On the BOF market, there is more and more the demand to provide complete system responsibility. Which means optimizing converter- and refractory-technologies with the aim to increase their life-times in parallel as a system. This is a new challenge for all parties involved (operation of steel plant, supplier for converter and refractory).

Under this scenario Danieli Corus can offer important features and improvements to the market:

> Maximum increase of converter size respectively inner reaction volume while leaving the main dimensions of the existing plant unchanged.

> The suspension system has to be designed in a manner that it is not limiting the life time of the converter. In this regards the well-known vertical lamella elements have been further improved. For the horizontal loads, Danieli developed and patented a new suspension element, which is based on flat lamella plates which compensate the thermal expansion of the vessel by elastic deformation.

> To increase the life time of the vessel shell, Danieli Corus applies in a recent project the features of high creep resistance converter shell material, converter air- and water cooling.

> For monitoring the temperature, Danieli Corus further developed the second generation of the temperature monitoring system Q-TEMP 2.0. This is a direct outcome of the above mentioned synergies.

> Another feature is the Danieli Conditioning Monitoring System (DCMS), which actually will be installed in a converter tilting drive. This system is giving online feedback of the actual condition of the gear components and defines the optimum timing for overhauling, repair or exchange of components or parts.

Keywords: Steelmaking Converter, BOF-Converter, Suspension System, Lifetime, Converter Cooling System, Condition Monitoring System.

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1 INTRODUCTION

Danieli entered the converter business in 2011 with the inception of the new, dedicated business unit Danieli Linz Technology. Since then five BOF converter vessels have been installed and are in operation world wide with heat sizes from 80 t to 180 t up to 350 t. Another 300 t converter is currently under fabrication.
Since July 2018 the converter technology has been fully integrated into Danieli Corus located in Ijmuiden in Netherlands. Danieli Corus is already well known in the iron- and steelmaking-market and very successful in blast furnace technology and is market leader for the sublance together with one of the most advanced level 2 systems.
With this new set–up of integrating the experts of Danieli Linz into the Danieli Corus group, a great opportunity has been launched for further developing equipment in oxygen steelmaking. On top of that, it is also unique that engineers of an equipment supplier of two disciplines (iron- and steelmaking) are working together in a single location. This opens new opportunities for the joint development of euqipment- as well as software-solutions for optimizing blast furnace- and converter-technologies in terms of costs, maintenance and resource savings.

Comentado [JRB1]: equipment

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. For optimization, the reaction volume should be increased as much as possible. The characteristic benchmark is the specific volume (defined as ratio of inner reaction volume to mass of liquid steel [m3/t]) which should be maximized up to a value of 1.0.
For this approach a lot of experience is necessary, because several boundary conditions have to be considered, such as: taken care of the clearance to the teeming ladle during tapping, up to the offgas system as well as the charging and tapping procedures and keeping the tilting torques and the foundation loads within certain limits. Some iterations in the engineering phase have been studied in order to find the right solution.

A typical example is the 350 t BOF revamped for ArcelorMittal Dobrava Gornicza (Katowice). There the inner volume could be increased from 225 m³ to 275 m³. This comes along with an increase from a specific volume of 0.64 to currently 0.79. Figure 1 shows the existing vessel and the new vessel.

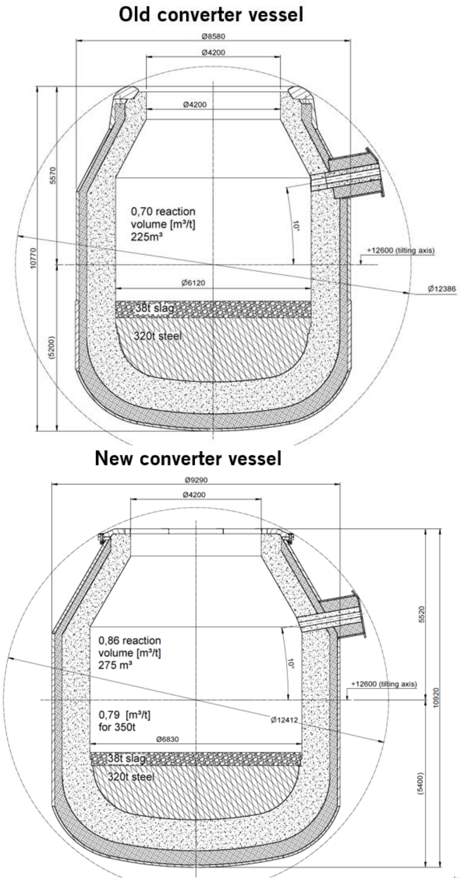


Figure 1. Comparison converter before (left) and after (right) revamping.

Comentado [JRB2]: up - down

3 SUSPENSION SYSTEMS

The suspension system is very important for a smooth production during the life time of the vessel shell.
The targets for the suspension system are:

> Keep the vessel shell in position at all time and during all process steps.
> Withstand all possible conditions which can happen, such as high temperature, water shocks, mechanical impacts, burn troughs, solidified steel bath, etc.
> Be maintenance free, which is the most challenging issue.

In principle, the suspension systems can be subdivided into vertical- and horizontal suspension elements. This is characteristic for all the modern converter suspension systems available on the market for a certain size (> 50 t). For that reason, the suspension elements are separated according to their loadings.
For the vertical loads Danieli applies the well-known and already in many plants installed lamella-type suspension elements. However, even for those, Danieli further improved the existing design in order to have a better load distribution in the

elements which should also increase their life time (see Figure 2). The thermal expansion as well as the long term deformation are compensated by elastic deformation of the lamella elements.

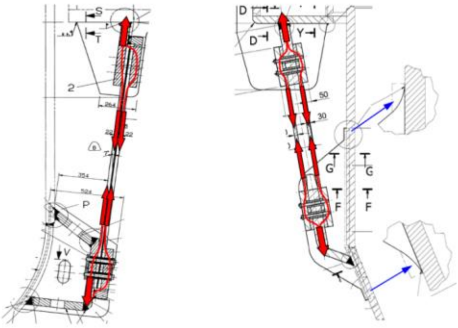
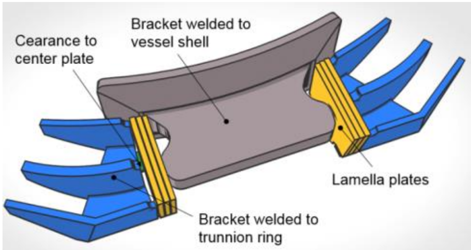


Figure 2. Conventional Lamella type element element (left), Danieli type vertical element (right).

The horizontal loads are typically carried by only 2 elements, which coincidentally are the most critical ones. Danieli developed a new element type, the so called DANIELLA-element (see Figure 3). There is a center bracket welded to (respectively into) the vessel shell and 2 brackets welded to the trunnion ring. In between there are elastic lamella plates arranged that show a small gap (2 – 3 mm) to the center rib of the trunnion ring bracket. The lamella plates do not have a fixed connection to any bracket but are just held in positions shown in Figure 3.
During vessel heating at start of a campaign and during production, the vessel brackets are exposed to higher heat impact and consequently temperature then the rest. This differences in the thermal expansion is compensated by elastic deformation (bending) of these plates within a provided clearance to the center plate (see Figure 3). The long term deformation of the vessel shell (creep) is not hindered at all in this DANIELLA element and consequently do not cause any additional stress or deformation in the system.



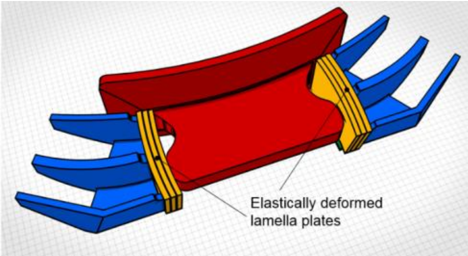


Figure 3. "DANIELLA element" in cold (left) and warm (right) condition.

Comentado [JRB3]: up - down

Based on this principle the DANIELLA element is built up by a simple and very robust welded structure without using of special elements like bearings, forgings or castings. This leads to the fact that a possible repairs can be carried out by the regular maintenance team of the steelplant, which minimizes downtime and costs.
Figure 4 shows the installation of the Danieli suspension system based on the horizontal DANIELLA element as well as the vertical lamella type elements as well as a detail of the Daniella plates.

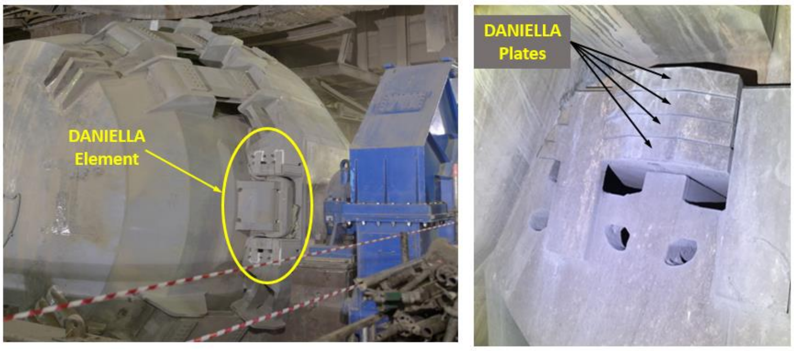


Figure 4. DANIELLA suspension system (left: during installation; right after 1 year of operation).

The following advantages of the DANIELLA suspension system can be summarized:
> Simple and very robust design
> No special parts involved (any repair can be done by maintenance staff only).
> Lamella plates are just inserted between welded-on brackets and are just kept in position by holder plates. Thus, these plates can easily be changed in case of an emergency or in case the clearance of the element is of interest to be changed.

Currently Danieli has revamped and upgraded following BOF converters (see Table 1):

Table 1. References

Plant	Tap Weight	Start–up
ArcelorMittal Dobrava Gornicza	350 t	May 2014
Aperam Timoteo	80 t	Dec 2015

ArcelorMittal Krakow	155 t	Nov 2016
ArcelorMittal Kryviy Righ	160 t	Aug 2017
ArcelorMittal Galati	180 t	Dec 2017
ArcelorMittal Temirtau	300 t	2019
USIMINAS Ipatinga	180 t	2020

All these BOF's are tailor-made based on best practice, input from enduser and other requirements. The design varies from fixed bottom, detachable bottom, welded and bolted top cones, with and without knuckles section, up forced draft air and water cooling (see figure 5).

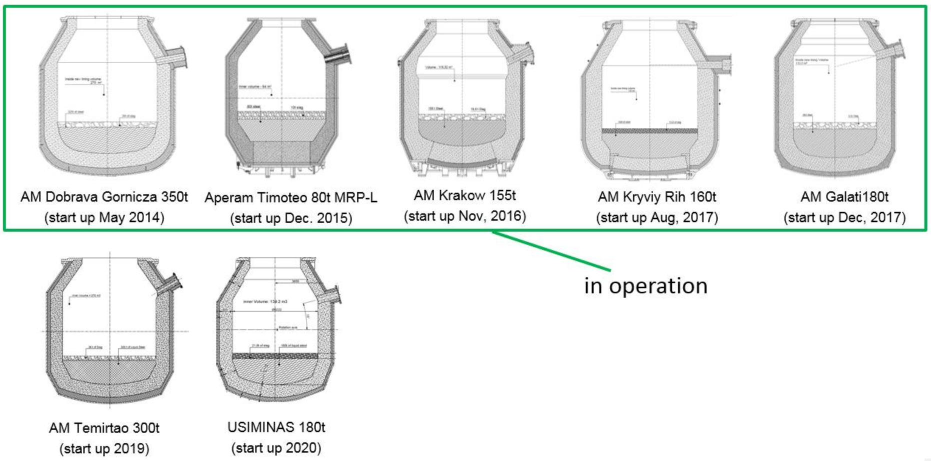


Figure 5. References.

4 CONVERTER LIFE-TIME

The life time of a converter vessel has always been an important factor for the steel producer. In parallel the life-time of the refractory is a key factor for the production and is directly influencing the cost of produced liquid steel. While for the converter life time the temperature of the vessel shell should be as less as possible the longer the refractory is in operation the higher is the shell temperature. So, those two demands are in contradiction and are challenging the steel producer in order to find the optimum, which is, of course depending of several parameters and different for each and every plant.

On one hand there is the task to keep the converter running at minimum temperature and expand its life time to a maximum in order to safe installation cost of a new converter. There are life times of up to 40 years possible but the refractory has be kept to a certain minimum thickness and maintained on regular basis.

On the other hand, there is the task to keep the refractory as long as possible in operation, which means mostly slag splashing and rocking at every heat with the results of to change the refractory just once a year or every two years. In this case, the converter vessel is overheated and does not last as long.

Finally all these decisions have been made by the steel-producer supported by the refractory experts.
However, there is a matter of fact, that converters are operated harder in terms of tap-to-tap-time (TTTT) these questions become more and more important even during the offer- but at least in the engineering-phase of a converter revamping project. Which comes along that also suppliers of the converter itself are involved in this decision making process.
But the possibilities to adopt the design, parameters or apply other options in the converter design are rather limited.
However, just recently Danieli Corus has been awarded with the exchange of a 180 t BOF in Brazil where all these factors have been essential for this order which are based on following components:

- Apply a high creep resistance material for the vessel shell
- Installation of the water cooling system for the converter top cone
- Installation of an air cooling system for the converter barrel section
- Installation of a temperature monitoring system for the complete vessel shell

4.1 Creep resistance material

Creep resistance steel, which can be applied for a converter vessel, is more or less limited to following pressure vessel materials (based on European Standards): (P355GH), 16Mo3, 13CrM04-4, 10CrMo9-10 and P420MHT. A comparison in terms of stress to reach 1% creep strain for a temperature level of 500° C is shown in Figure 6.

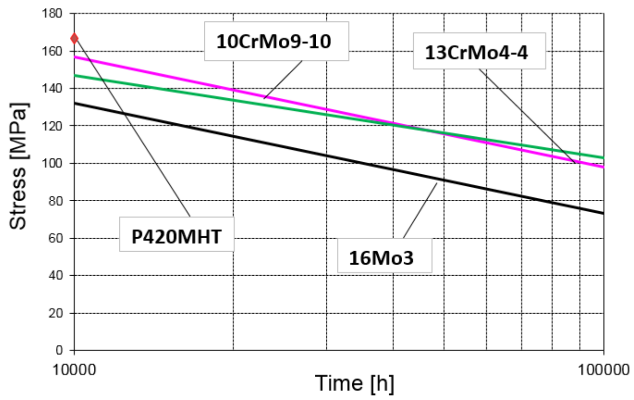


Figure 6. Stress for 1% Creep Strain at 500° C.

Very common material is 16Mo3. It has excellent mechanical properties up to 500° C, reasonable guaranteed creep resistance, is moderately easy to weld. The top players in terms of creep are the Cr-Mo-alloyed steel grades 13CrMo4-4 (ASTM A387 Gr.11) and 10CrMo9-10 (ASTM A387 Gr.22). Those materials show maximum creep resistance but require careful welding and post weld heat treatment (PWHT). This is basically not an issue for the supplier but has to be taken into consideration in case of e.g. repair on site to apply PWHT in situ. However, this material is already in operation for years in converters in North America and is now being more and more accepted also in other parts of the world.

A special case is P420MHT. This is a thermo-mechanical rolled steel grade and does not ask for PWHT. However, in case of overheating of this material during usage the mechanical properties might be lost or at least be influenced negatively. That's why this material is not preferred for an application in the BOF.

4.2 Top cone water cooling

There are always pros and cons to apply water cooling in BOF components but the water cooling as such is a very effective feature to reduce the temperature of the vessel shell. Particularly for the top cone, which is the most exposed part of the BOF in terms of temperature, the life time of the top cone can be increased seriously or sometimes even doubled. In some plants the temperature of the top cone (without cooling) is so high that this part becomes almost a wear part. However, this system is exposed to extreme conditions which comes along with leakages in the system demanding periodical maintenance

4.3 Air cooling of the barrel section

Air is of course a less effective cooling media than water, but for the barrel section this is a suitable alternative. The barrel section is of utmost importance, because the deformation in this area define the end of the life time of the converter body (vessel shell can even touch the trunnion ring).
Such cooling is working on the principle that the air streams trough hundreds (even thousands) of holes in air-panels or at the inside of the trunnion ring web plates into the air gap between trunnion ring and converter and touches also the vessel shell. This air flows destroy the natural air flow within the trunnion ring gap and provides turbulences and finally a mixing of the hot air with the cooler one and increases also the convection factor outside the vessel. The air cooling is more effective at higher temperature of vessel shell, which comes along with the fact, that creep gets relevant from temperatures more than 400°C.

4.4 Converter temperature monitoring system (Q-TEMP)

Another feature to prolong the converter life time is a feedback of the temperature of the vessel shell. Danieli has already installed a converter temperature monitoring system, the so called Q-TEMP, on an 180t BOF in Ukraine. However, this installation had to be further improved in terms of life time of the sensor which are based on thermos-resistance elements as well as better access.
Based on the experience of Danieli Corus iron-making team, were similar applications are successfully installed on blast furnaces and the experience from BOF application, the next generation of Q-TEMP 2.0 was developed and will be applied in the new BOF in Brazil. So, this is a direct success of the new set-up of the BOF group within Danieli Corus which comes along with advantages for the enduser. This system is based on two different measurement methods. In the area with no direct visual access (top area) thermo-couples are arranged directly on the vessel shell. In the area of direct visual access the temperature is measured by infra-red cameras (see Figure 8).

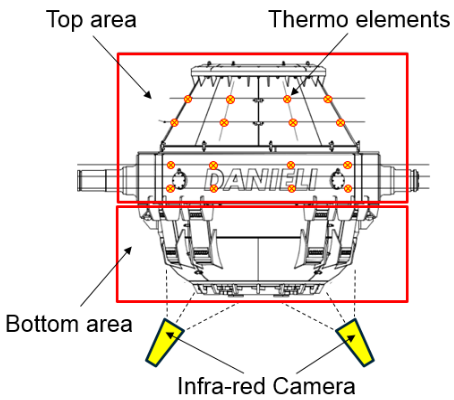


Figure 7. General Arrangement of the Danieli Temperature monitoring system Q–TEMP 2.0.

There are 32 thermocouples arranged in 4 horizontal rows on the vessel shell. The data is transferred via hard wired cables through the trunnion ring to the outside of the trunnion pin. Form there a WIFI-connection is provided for further processing the data. Additionally, the recorded data are saved in a hard drive and displayed on screen in the main pulpit (see Figure 9).

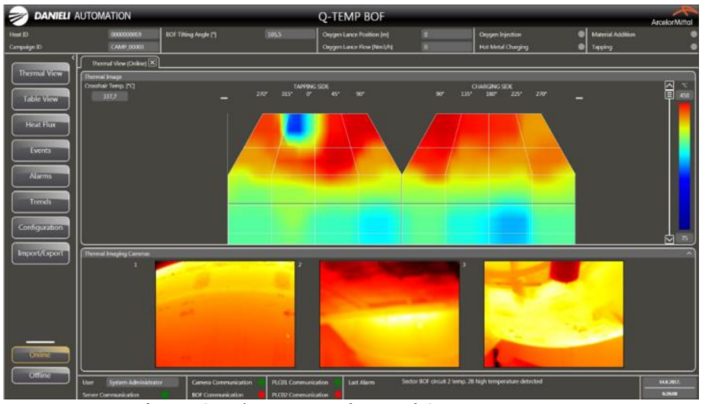


Figure 8. Print screen of HMI of Q-TEMP system

Q-TEMP 2.0 has following new features (see Figure 10):

> Usage of thermos-couples instead of thermo resistance elements

> All thermo couples can be maintained and exchanged from inside the trunnion ring.

> All these elements are arranged in such a way that those can follow all vessel shell deformation (permanent contact of the elements to vessel shell is given)

> Not necessary to remove slag shields for maintenance of the protection piping of the elements

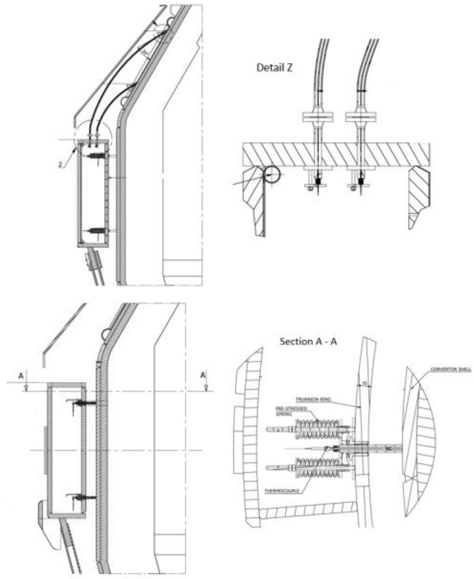


Figure 10. Arrangement of the thermocouples on top cone (left) and barrel section (right) of Q-Temp 2.0

All these features are applied in the new state of the art converter for Brazil. Figure 7 shows a general arrangement of this BOF.

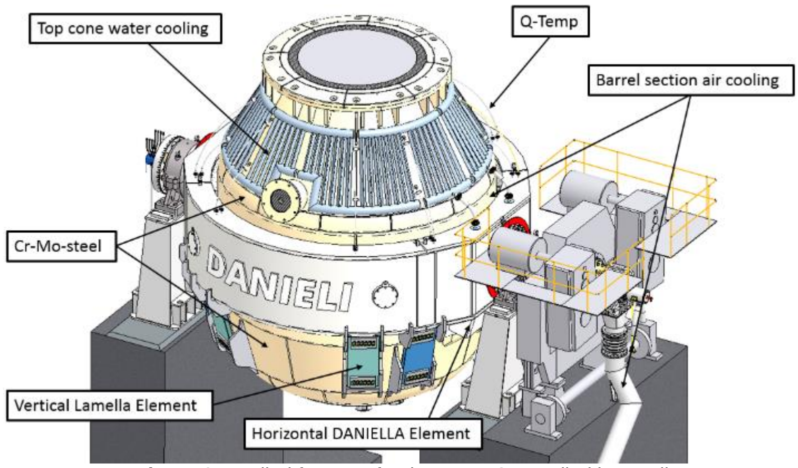


Figure 9. Applied features for the new BOF applied in Brazil

5 DANIELI CONDITION MONITORING SYSTEMS (DCMS)

In the modern challenging steelmaking scenarios, there is common focus on cost reduction while maintaining high plant availability and reliability. This is somehow a contradiction because on one hand maintenance reduces the operation time but avoids total failures of components which can create major shut downs and disabling production. Hence, there is an optimum of how much maintenance should be applied. In principle three types of maintenance are applicable:

a) **Breakdown or Emergency Maintenance:** Repair or change of components in case of breakdown. Most risky and can cause major shutdown in case of missing spare parts or complicated and time consuming repair → should be avoided.

b) **Preventive Maintenance:** is applied on regular basis when a machine or components are overhauled in specified time intervals regardless of the condition of the parts.

c) **Predictive Maintenance:** the maintenance requirement is determined by continuously analyzing the condition of the machine or components in order to predict and schedule the most efficient repair action prior to failure

The predictive maintenance is based on measuring of machine vibrations in dedicated locations. These vibration are measured by means of acceleration-sensors installed directly on the machine body. These data are then managed by the DCMS in an automatic- or sampling mode. Particularly the sampling mode is configurable on DCMS server in different modalities.

Each vibration data will be synchronized to the machine movements and rotations of components in order to define the relation of the vibration signals with the working condition of each equipment.

The server collects the data and performs on-line processing, data archiving and post-processing. The vibration values acquired during machine working condition are compared with the prefixed thresholds limit for automatic alarm generation and management.

In case a certain threshold limit is reached, a dedicated information will be sent to a nominated person in charge of this equipment as well to Danieli. The Service team of Danieli will then start a root cause analysis, which means further analyze this signal based on historical data as well as experience. When the reason has been identified Danieli will contact this customer and provide information which component(s) should be changed within when in order to avoid further damages or unplanned stoppages.

In the area of BOF, this system can be typically applied in the converter tilting drive (bull gear and primary gears) as well as in the main bearings. An overview of such an application is shown in Figure 11. Recently Danieli got an order to install a DCMS in a BOF tilting drive for Shougang in China. This confirms the positive effect of this system and will further improve the BOF steelmaking equipment.

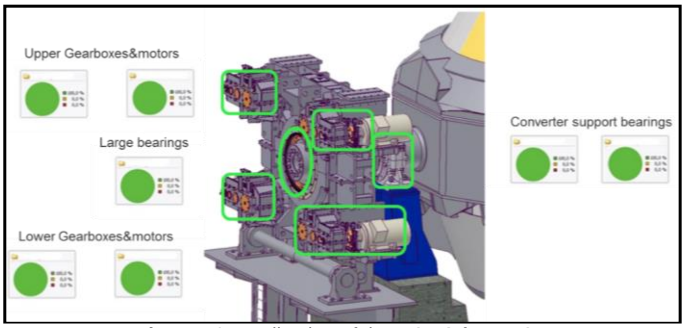


Figure 10. Application of the DCMS for a BOF

The main benefits of a Condition Monitoring system supplied by the equipment OEM are the following:

- Dedicated system engineering for sensors location and hardware configuration for the correct data processing
- Specific threshold limits configured according with drive train components
- Service support focused not only to detect possible defect at early stage but to identify the correct maintenance action to be scheduled

6 CONCLUDING REMARKS

Since its launch in 2011 the converter division of Danieli Corus, with the aim of improving process efficiency and lowering capital and operating costs, has revamped/redesigned five converters and is working on further two.
Synergies with the iron-making team of Danieli Corus group, is allowing to facilitate further developments of technical solutions, such as the case of Q-temp 2.0 as well as creating new ideas by combining different points of view and experiences.

Actually Danieli Corus has been awarded for a 180 t BOF in Brazil. This converter is equipped with several features in order to prolong the life time as much as possible. In this regards it represents the latest development and shows the state of the art converter for the time being.

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