The VAI-CON® Link Suspension System from Development to Six Years of Experience

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Summary:
Since the invention of the LD process in 1949 by VOEST-ALPINE in Linz, Austria, VAI has continuously improved the process as well as the equipment itself. One of the most important parts of the modern converter equipment is the converter suspension. Since the very beginning VAI has developed and applied statically determined suspension systems. This means the converter is stably suspended in the trunnion ring, but any deformation, caused for example by thermal expansion or long-term deformation, is not hindered at all. Hence, no additional stresses are introduced to the system from deformation. In the beginning a bracket type system was used, and later the so-called VAI-CON® Disk system was applied very successfully. The increase in the revamping business of recent years, however, has led to the development of a new suspension system—the well-known VAI-CON® Link suspension system. The first installation went into operation in December 1997 in a 170-ton LD converter at ISPAT ISCOR Newcastle in South Africa. VAI currently has 24 references worldwide. The suspension system runs completely free of maintenance. The solid design of the suspension elements even allow them to withstand burn-throughs without any major damage. Even when they come into direct contact with liquid steel, the main components are not damaged at all and need not to be replaced. Experience gained at ISCOR and SSAB Lulea (Sweden) has demonstrated this impressively. This paper describes the results of a system inspection after five years of operation. The largest North-American steel producer, US Steel, has recently decided to install this system in a 180-ton LD converter at Kosice in the Republic of Slovakia.

Keywords: converter, suspension system, revamping, maintenance free

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1 Introduction

At the beginning of the 1990s VAI ambitiously began the development of a new converter suspension system for stationary LD converters (BOF). The standard suspension system for VAI had been the well-known VAI-CON® Disk suspension system, which was developed during the 1970s,resulting in a total of 23 references. It is 100% maintenance-free and incorporates most of the basic requirements of an ideal converter suspension system. Two important features were improved in the following manner:

- The area of force introduction to the vessel shell was decreased.
- The gap between the converter vessel shell and the trunnion ring was decreased.

These changes provided the challenging boundary conditions for the new development, in which all the advantages of a modern suspension system were incorporated.

2 Development of the VAI-CON® Link Suspension System

The breakthrough of the new system was in applying a industrial proven element of the VAI-CON® Disk suspension system the so-called toggle link. The toggle link transfers the tilting torque from the vessel shell to the trunnion ring. **Figure 1** shows the VAI-CON® Disk suspension system of the 300-ton LD converter installed at the Gwang Yang works in South Korea. The most important components of the VAI-CON® Disk suspension system are the two disks which are bolted to the trunnion ring in the area of the pins, the disk eye and its star-ribs (welded to the vessel shell) and the toggle link that is equipped with spherical plain bearings. These components are all maintenance-free and have been in operation for more than fifteen years.

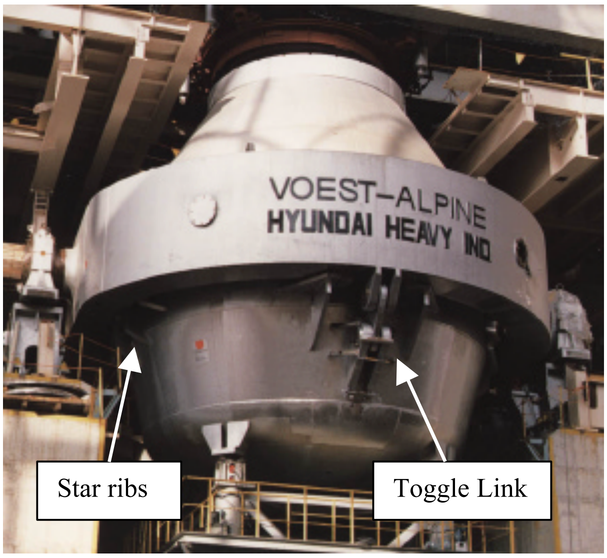

Figure 1: 300-ton LD converter with VAI-CON® Disk suspension system showing the toggle-link

2.1 History of the Toggle Link and Spherical Plain Bearings

VAI has a long tradition of using spherical plain bearings in the converter business. At the beginning this type of bearing was used for exchangeable converters in a three-point suspension system. The bearings were positioned on large pins which compensated for the thermal expansion of the vessel through axial movements between the pin and the inner racer of the bearings. The bearings were greased in order to guarantee smooth movement; however, this lubrication was not effective because the grease was soon worn and the pin seized in the bearings. The bearing design was consequently changed from sliding contact to swivel contact. This was an important improvement in the development. The link between the trunnion ring and the converter with two bearings on its end transformed any deformation (e.g. G_1-G_2) of the vessel into very small swivel movements (rotational deformation) $\Delta\varphi$ in the bearing itself (see **Figure 2**).

$G_1 - G_2 \rightarrow \Delta\varphi$

Example: A typical mid-size converter (180 t) with a vessel-shell diameter of d = 7500 mm and a link length of 150 mm is assumed. It is also assumed that at the end of campaign the vessel shell has a temperature of 500°C. For worst-case estimation, the trunnion ring should be water-cooled with a maximum temperature of 80 °C.

The following formula applies to a room temperature of 20°C and
α ... thermal expansion coefficient of 1.2 10^5:

$$G_1 - G_2 \approx \alpha \frac{d}{2} \Delta\vartheta = 20.25 mm$$

$$\Delta\varphi \approx \frac{(G_1 - G_2)}{L} \frac{180}{\pi} = 0.77° = 46'$$

This extreme small swivel angle and the long time in which this angle occurs (from room temperature to maximum temperature at the end of campaign) render any lubrication or grease completely useless. So even with the assumption of a highly heat-resistant grease, no hydrodynamic film condition can be applied on a long-term basis. Hence, it was decided to forego the possibility of lubrication from the very beginning. This was entirely in line with the target of developing a maintenance-free system. However, to ensure that the bearing would be able to withstand these conditions for long periods of time, the bearings would have to have the following features:

- enlarged clearance in the bearings
- thermal stabilized bearings up 300°C
- coated bearing surfaces
- oversized bearings (decreased allowable capacity)

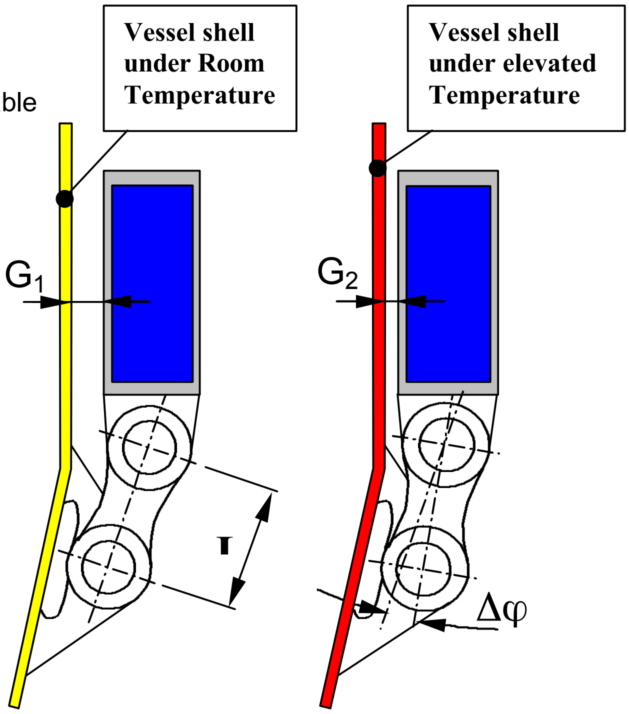

Figure 2: Principle of Toggle link, transforming transversal displacement in rotational displacement

These features were developed by VAI and a well-known German bearing supplier (ELGES). The result was to specially treat basically standard steel/steel spherical plain bearings to make them completely maintenance-free and to implement them in a steelmaking converter. The VAI-CON® link bearings are important factors for the success of the VAI-CON® Link suspension system.

2.2 The Link Element

As mentioned above, the main task of the link is to compensate for deformation of the converter by transferring radial converter deformation into a swivelling motion. For this reason the link is equipped with two spherical plain bearings on both ends. In this manner the link can only transfer unidirectional loading. Any bending, torsion or shear load can generally not be introduced to the link. The link itself is of solid design and can withstand these extreme conditions in a converter suspension system. High vessel shell temperatures of up to 500°C lead to stress of unknown magnitudes, large amounts of dust, contact with slag or liquid steel, and the appearance of water. Typical materials for the link are 21CrMoV57 or ASTM B 193 B7, which are well-known bolt materials for applications at highly elevated temperatures.

2.3 Inside the VAI-CON® Link Element

The link is supported by a spherical plain bearing on a plain pin which is supported in two lugs. Two side bearings are also used to provide ease when inserting the pin. These also compensate for any misalignment of the lugs, such as shrinkage during welding, etc. The two side bearings are smaller as compared to the main bearing (because they assume only half the load). A bushing between the main bearing and the plain pin compensates for the resulting distance in the diameter.

The VAI-CON® Link arrangement is shown in **Figure 3** and consists of:

- Link
- spherical plain bearings
- pins
- lugs welded to the vessel shell and trunnion ring

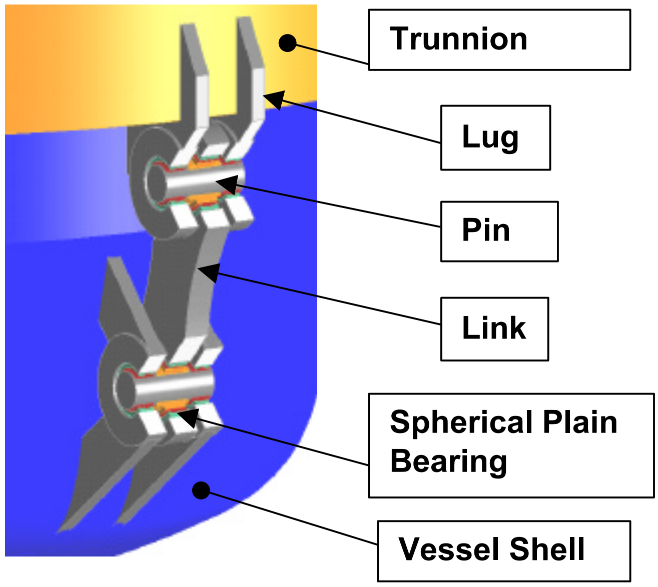

Figure 3: Details of link Arrangement

The detail of the bearing arrangement is shown in

Figure 4.

The bearings are protected by heavy cover plates against contact with liquid steel, slag, dust, etc. The pin itself is sealed with Fey rings and a heat-resistant oven rope with a holder ring against impact with slag, liquid steel or heavy dust. **Figure 5** shows the actual link arrangement.

2.4 The VAI-CON® Link Suspension System

VAI has been gaining experience in the converter business for more than 50 years now. The philosophy has always been to have a statically determined suspension system [1], [6]. The link element is consequently arranged on the converter to generate a statically determined suspension system. The well-known VAI-CON® Link suspension system consists of three vertical links, two horizontal links and a stabilizer. These six elements ensure that all six degrees of freedom (DOFs) of a body in space are determined at any given time. Any additional support would generate an over-determined system, which must be avoided at all cost.

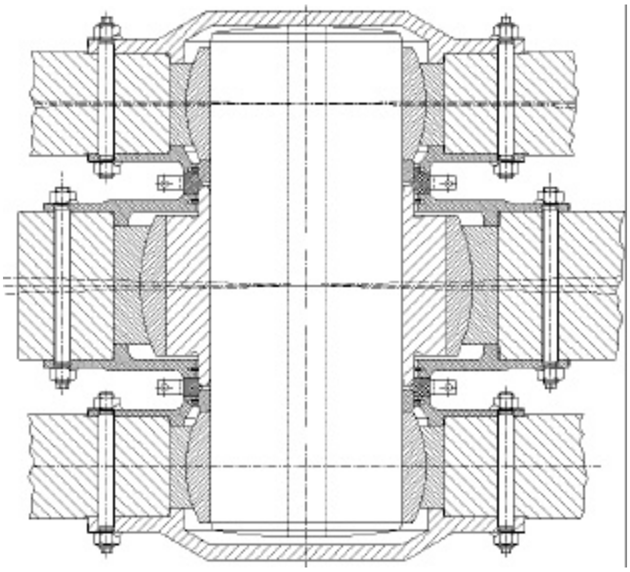

Figure 4: Cross Section of Bearing Arrangement

Figure 5: Vertical link arrangement

The first installation went into operation in December 1997 in a 175-ton LD converter at ISPAT ISCOR Newcastle in South Africa. The existing trunnion ring (of NIPPON Steel design) was re-used. This installation was followed by another four installations in South Africa and one in Europe in 1998. This amounts to a total of six years of experience, which was an opportune time to obtain feedback from the installed systems. **Figure 6** shows the initial installation of the VAI-CON® Link suspension system at ISCOR Newcastle in South Africa in an existing trunnion ring (Nippon Steel) in December of 1997.

2.5 Inspection of the VAI-CON® Link Suspension System at ISPAT ISCOR Newcastle

During the first quarter of 2003, VAI inspected the LD converter and the maintenance group at ISPAT ISCOR Newcastle in order to obtain more information on the behaviour of the system after more than five years of operation. The converter was put into bottom-up position in order to better access the links. All slag-protection boxes of the three vertical links were opened (the two horizontal links and the stabilizer are not protected). General visual inspection of the system showed that the equipment is in good condition, though skull formations were found in some locations between the lugs and the links. This is due to normal operation and is no cause for concern. Nevertheless the skull was removed. It was also noted that all the links were in a more-or-less arbitrary position. The spherical plain bearings on both ends provide each link with two free DOFs. There is possible rigid-body rotation around the length axes of the link as well as the cross axis that is normal to the vessel shell (see also **Figure 7**). The arbitrary position indicates that the spherical plain bearings are functional.

The weld seams between the lugs and the vessel shell and the trunnion ring as well as the welds of the lugs themselves were all cleaned and checked (VT[1], MT[2] and UT[3]) by an external expert (see also **Figure 7**) The test results were very positive; no problems were detected at all. Some protection

[1] VT ... Visual Test
[2] MT ... Magnetic Particle Test
[3] UT ... Ultrasonic Test

covers were removed in order to be able to inspect the condition of the spherical plain bearings. This is shown in
Figure 8.

Figure 6: First installation of the VAI-CON® Link

Suspensions at ISCOR Newcastle (South Africa) on an existing trunnion ring (Nippon Steel) in Dec. 1997.

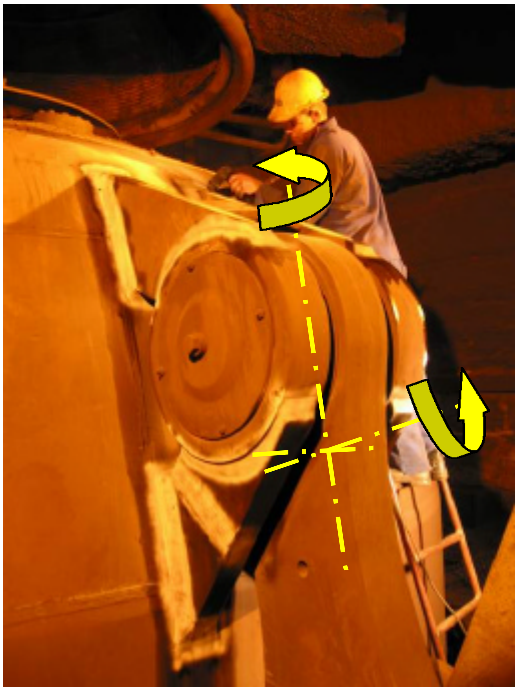

Figure 7: MT of vertical link arrangement.

The arrows show possible rigid-body rotations of the link.

The bearing and pin are in very good condition. There is more or less no difference in the situation during erection. A check of the clearance between the inner and outer racer of the bearing has shown that there is some dust accumulation in the bearing. 100% sealing cannot be achieved. However, dust does not disturb the function of the system. The major task for the main bearings is to allow unhindered deformation of the vessel shell. Converter deformation is generally caused by thermal effects. (Even creep is caused by temperature changes.) The restriction of thermal effects would require extremely high loads or forces. It is obvious that no dust formation in the bearings (whatever the extent) is able to withstand converter deformation. A certain minimum amount of force would be required to break the bearing loose, but movement cannot be hindered completely. For this reason the vessel shell will deform even when friction is involved.

The dust has no negative effect at all on the side bearings. As mentioned above, the task of the side bearings is to perfectly align the centre lines of the bore holes of the side lugs with those of the link only. The side bearings no longer have any function once the pin is inserted. So dust formation in the side bearings may also be useful.

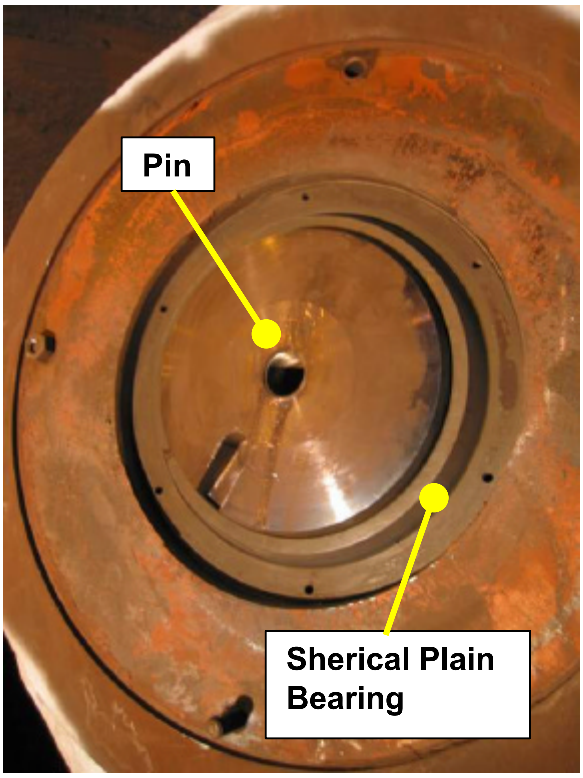

Figure 8: Vertical link with removed protection cover

An example of the horizontal links is shown in **Figure 9**. The link is rotated by a certain angle indicating a right function of the main bearing. Some skull formation and dust accumulation are visible between the lugs and the link. Particularly in Newcastle the horizontal links are additionally exposed to temperature shock (the arrangement is shown in **Figure 10**). Primarily they are exposed to high temperature (under regular operating conditions) but additionally to water leakage from the offgas hood. The system can withstand these influences as well. The horizontal link arrangement shows some rust formation (even on the bearings). However, due to the solid and heavy design, any stress-corrosion or any other corrosion does not negatively influence the system. Rust in the main bearings have more or less the same effect as dust, just increasing the friction effect in the bearing (see above).

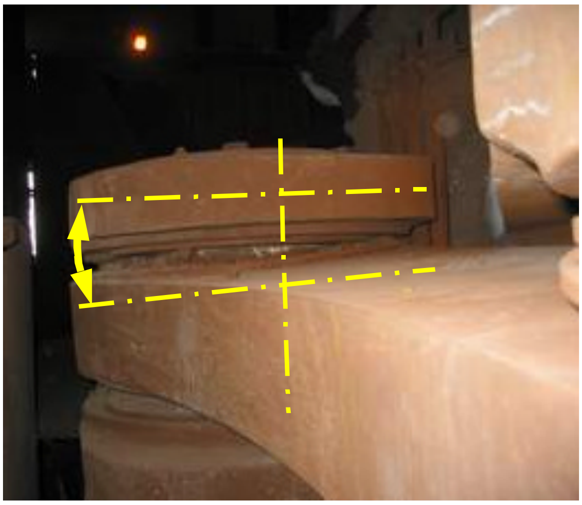

Figure 9: Horizontal link with swivelled link showing the function of the spherical plain bearing .

Figure 10: Horizontal link arrangement.

3 Experience with the VAI-CON® Link System under Operating Conditions

The VAI-CON® link system is industrially proven and has shown its reliability with several references. The range worldwide ranges from small-size 55-ton to regular-size 180-ton and huge-size 375-ton converters. The maintenance personnel have all reported that the system is truly 100% free of maintenance.

It can be shown as well, that the system is 100% stable in any converter position and there is no rocking or sliding movement possible. The system immanent clearances in the bearings are not recognized at all. However, they are temporally closed with dust after a while. The system withstands regular and even irregular operation conditions (e.g. shock loads to due skull cleaning with full scrap shut, water infiltration, etc.).

A typical temperature scenario is shown in **Figure 11**. It can be seen that the lugs operate much like cooling ribs as well. This has a positive effect in that the main bearings as well as the link are exposed to much less heat as compared to the vessel shell. A temperature drop of 100 °C can be observed along the length of the lugs between the vessel shell and the bearing housing (see **Figure 12**).

Even under high temperature conditions (end of campaign), the maximum temperature measured in the area of the bearing is not more than 220 °C, which is a conservative comparison when looking at the design criteria of the spherical plain bearings (compare section 2.1).

3.1 Experience under Extreme (Abnormal) Operating Conditions

ISPAT ISCOR Newcastle is also a good example of extreme operating conditions. A serious burn-through occurred in LD Vessel #2 after only one half year in operation. It occurred directly behind the trunnion ring during a regular hand-sampling process with the converter tilted approximately 90° in charging direction. The liquid steel burned a hole in the vessel shell and into the inner web plate of the trunnion ring. There was a large explosion when the liquid steel came into contact with the water from the trunnion ring water cooling system. After that the outer web plate of the trunnion ring was also burned through. The vertical and horizontal link came into contact with liquid steel. There was no personal injury; however, the vessel shell, the trunnion ring, the piping and slag shields were heavily damaged.

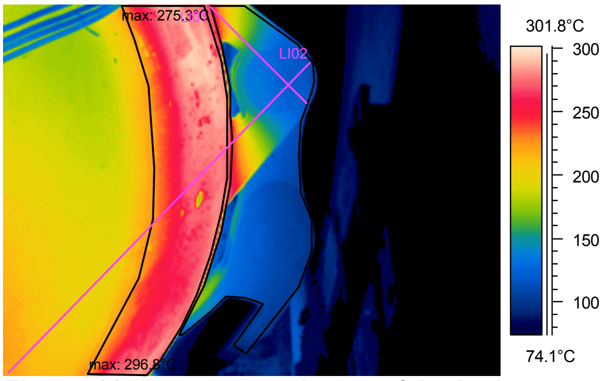

Figure 11: Temperature image of the horizontal Link arrangement (ISPAT ISCOR Vanderbijlpark).

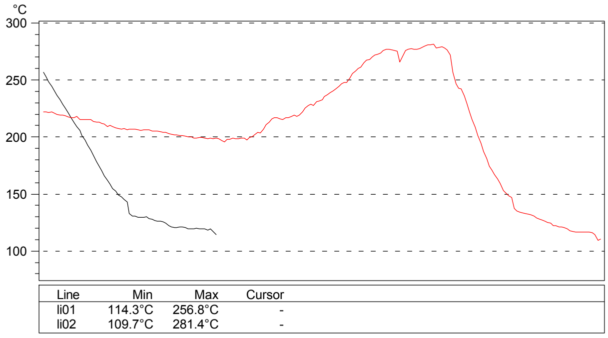

Figure 12: Temperature graphs along path defined above.

An inspection of the suspension system showed another major advantage of the system. The heavy structure and solid dimensions of the adjacent parts cause liquid steel to instantaneously freeze and cover the parts with a solid steel skin. The huge masses of the involved suspension system have a very high heat capacity as well. The transient heat scenario thus causes the liquid steel to solidify quickly. For this reason there are high heat effects on the surface only. The equipment is usually not washed.

Figure 13: Solidified liquid steel on horizontal link arrangement after a burn-through

Figure 13 shows the horizontal link arrangement after a burn-through. The solidified steel automatically separates from the equipment after cooling down (caused by the temperature gradient in the frozen steel). This is an additional feature of the VAI-CON® Link system. It withstands the most stringent operating conditions. Burn-throughs are a nightmare for every steel producer but cannot be completely avoided (Murphy's law). The equipment—particularly the links—were also checked through measurements of the surface hardness. However, the loss of hardness was acceptable, so no part of the suspension system was replaced after this serious burn-through. It took roughly two months to repair the vessel shell and trunnion ring. This behaviour must be taken into consideration when the question arises, "What happens when a link is missing?" It has been proven that not even a serious burn-through will destroy a link.

4 Conclusion

Since the invention of the LD process by VOEST-ALPINE, VAI has continuously developed and improved the process as well as the equipment Particularly the suspension system is one of the most important mechanical parts of the core converter equipment. The philosophy of VAI always was to apply a suspension system that is statically determined. With such a system the converter is free to expand and no extra stresses or unknown loads from hindered expansion as well as long term deformation occur.

VAI began with bracket-type suspensions systems. This system was based on wedges that had to be adjusted from time to time. Hence, it was not entirely free of maintenance. The next generation was the so-called VAI-CON® Disk suspension system. The tilting torque was introduced at the beginning through a toggle pin element. The continuous development process and experience gained from exchangeable converters yielded the concept of the toggle link. The introduction of this element made the VAI-CON® Disk suspension system maintenance-free. VAI used this technology to develop a new suspension system based on this link element alone.

This was the birth of the so-called VAI-CON® Link suspension system. In December 1997 this system went into operation on a 175-ton LD converter at ISPAT ISCOR Newcastle in South Africa. It was applied on an existing trunnion ring (NIPPON Steel design). The system was inspected at the beginning of 2003 in order to verify the performance and confirm that the system was free of maintenance. The complete suspension system and the welds to the vessel shell and trunnion ring were inspected and tested with MT and UT. No problems were found, and the suspension system has been running continuously without any maintenance.

4.1 Experience under Normal and Abnormal Operating Conditions

Experience after six and five years, respectively, has shown that the VAI-CON® Link system is truly free of maintenance. The other applications worldwide, from 55-ton to 375-ton converters have shown the same results. It was also verified that the system is completely stable. Even the temperature of the system is lower than expected even for high vessel shell temperatures (up to 500 °C); however, the system functions excellently at all reference plants throughout the world (55 t to 375 t).

An additional advantage is the experience at ISPAT ISCOR Newcastle. Here there was a serious burn-through behind the trunnion ring on charging side one year after commissioning. The liquid steel severely damaged the vessel shell and the trunnion ring. The liquid steel even came into direct contact with the suspension elements. However, the liquid steel instantaneously froze when it came into contact with the heavy-duty elements. For this reason no suspension element was damaged, nor was it necessary to make any replacements at all. So there is an additional advantage of the VAI-CON® link system in cases of burn-through as compared to other suspension systems that are much more sensitive in this regard.

As a conclusion, the following is list of the verified advantages of the VAI-CON® Link system:

- The system is completely free of maintenance.
- The components are of solid design and resistant to contact with liquid steel (burn-throughs).
- There is maximum space for natural air draft.
- All components have been industrially proven for more than 20 years (VAI-CON® Disk system).
- Statically determinacy allows unobstructed vessel shell deformation.

4.2 References

Currently, VAI has already had six years experience with this system. The first system was installed at ISPAT ISCOR Newcastle in December 1997. Another five applications have already had five years of operating experience. Currently VAI has 25 references for this system worldwide (see **Table 1**) in existing trunnion rings (retrofit) and completely new installations. The system can be tailored to the particular needs in the plant and is very cost effective (saves investment costs).

Recently VAI was awarded an order by Belgo Mineira in Brazil, where the existing lamella-type suspension systems will be replaced by the VAI-CON® Link suspension system. The lamellas have been in operation for approximately 18 years and are characterized by a buckling phenomenon. This was one of the important reasons that Belgo made the decision to install the maintenance-free VAI-CON® Link suspension system.

PLANT	Heat Size	Retrofit	Startup
ISPAT ISCOR Newcastle, RSA	175	Y	12/1997
ISPAT ISCOR Newcastle, RSA	175	Y	6/1998
ISPAT ISCOR Newcastle, RSA	175	Y	2/1999
ISPAT ISCOR Vanderbijlpark, RSA	170	Y	7/1998
ISPAT ISCOR Vanderbijlpark, RSA	170	Y	9/1998
ISPAT ISCOR Vanderbijlpark, RSA	170	Y	12/1998
HUTA Sendzimira, Poland	150		8/1998
VOEST-ALPINE Donawitz, Austria	67		10/1999
VOEST-ALPINE Donawitz, Austria	67		4/2000
ILVA Taranto, Italy	375	Y	12/1999
ILVA Taranto, Italy	375	Y	7/2000
ILVA Taranto, Italy	375	Y	10/2000
SSAB Luleå, Sweden	120		7/2000
SSAB Luleå, Sweden	120		8/2000
COSIPA, Brasilia	180		7/2001
COSIPA, Brasilia	160		9/2001
COSIPA, Brasilia	160		1/2002
XINGTAI, China	55		12/2002
Zhangjingang, China	180		1/2004
Zhangjingang, China	180		3/2004
Zhangjingang, China	180		?/2004
CSN, Brazil	240	Y	10/2004
US Steel Kosice, Slovak Republic	180		?/2004
Belgo Mineira, Brasilia	110		?/2004
Belgo Mineira, Brasilia	110		?/2004

Table 1 Overview of current references worldwide.

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