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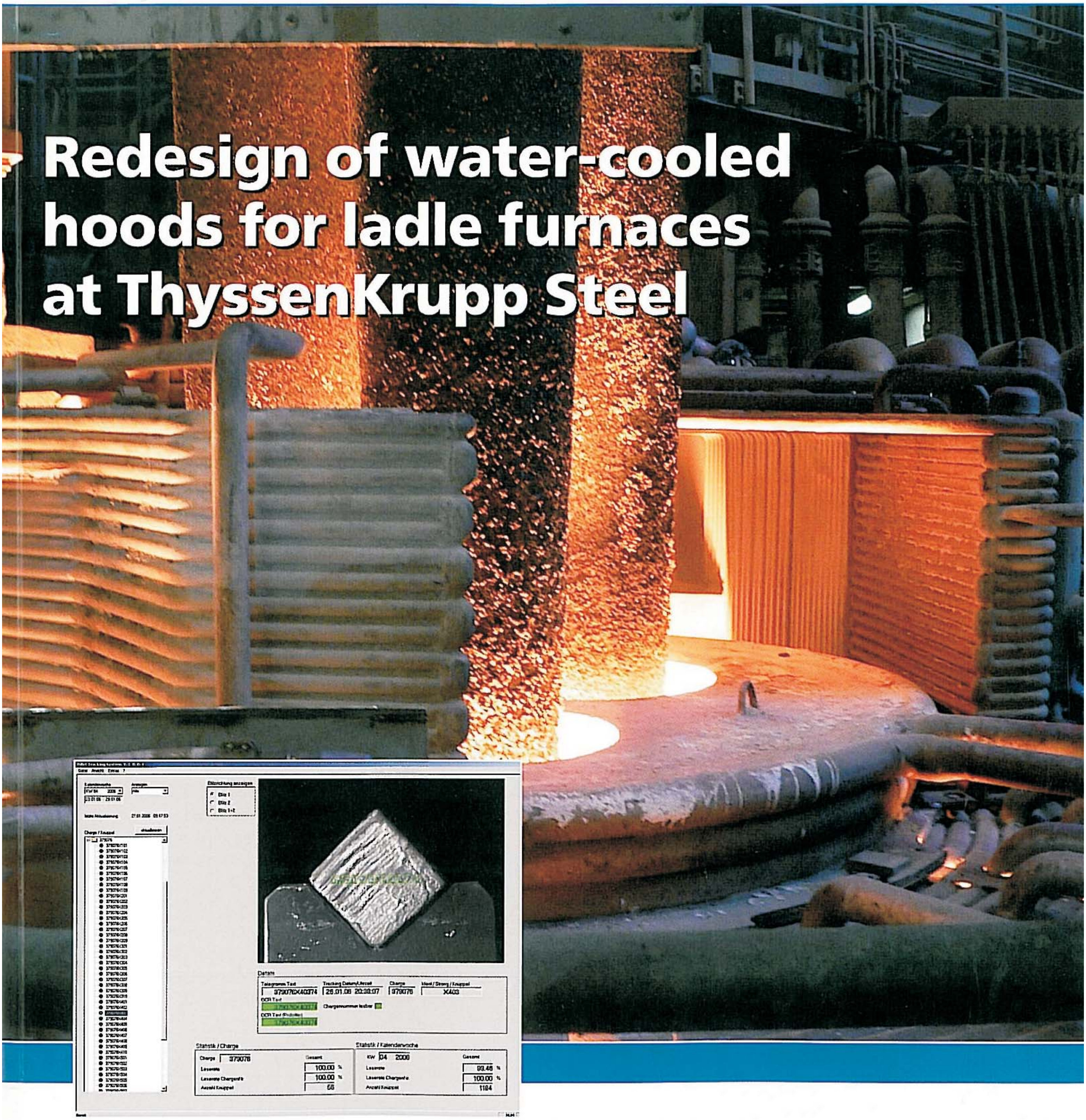

Redesign of water-cooled hoods for ladle furnaces at ThyssenKrupp Steel

Automatic product identification for the steel industry

Redesign of water-cooled hoods for ladle furnaces at ThyssenKrupp Steel

Avoidance of production losses due to equipment failure is where most optimization measures for existing plants start. Another trend is to maximize the intervals between cost-intensive maintenance and cleaning measures. These objectives can, however, only be achieved if the industry is willing to invest and introduce innovative technologies. A decisive factor for the success of such projects is regular communication between the plant builders and plant operators during the planning phase. This article describes a successful plant optimization project at ThyssenKrupp Steel AG in Duisburg, Germany, by way of the example of two redesigned ladle hoods.

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ThyssenKrupp Steel AG is synonymous with innovation in steelmaking and a world leader in the production of top-quality high-tech steels. At its Duisburg location, the company operates most modern production facilities using process technology of the latest state of art. The production equipment is subject to constant further development. Four high-capacity blast furnaces produce almost 12 million t/year hot metal which is processed into quality steel at the basic oxygen steel plants in Beeckerwerth and Bruckhausen. At Bruckhausen two converters with a heat weight of 380 t each supply one continuous casting plant and one casting-rolling plant with a total of 5 million t/year of crude steel.

Since 1999 the Bruckhausen steel works features a ladle furnace with two secondary metallurgy stations. They enable the production of highly demanding steel grades by setting the required steel analysis through objective decarburizing and alloying, precisely adjusting the casting temperature and by ladle slag reduction.

Situation prior to the modernization

The ladle furnace in the No. 1 basic oxygen steel plant in Duisburg Bruckhausen is made up of two treatment stations of almost identical, however mirrored, design. Both treatment stations are heated by a common electrode arm, which from its central position can swivel between the two stations. Each station is equipped with an own bunker and feeding system for alloying agents and three lances for argon purging, calcium metallurgy as well as temperature measurement and sampling.

The vertical movements of the hoods are actuated hydraulically with the hoods suspended as jibs. Arising fumes are removed of by a suction and filter plant. The bath level and the function of the porous plug for argon purging are monitored by a camera at both stands.

Since the ladle furnace was started up first, water-cooled hoods made of boiler tube have been used. The first-generation hoods consisted of two concentric ring headers as supporting elements of the construction. In the headers a flat roof in tubular construction was arranged. The roof had a central opening for the electrodes and openings for alloying additions and the lances.

The ladle was covered by a cylindrical radiation hood, which in the radiation zone near the bath level featured a construction of cooled tubes and rectangular pockets at the ladle lifting bail. Above the high-radiation zone this part of the hood was a non-cooled sheet construction mounted at the outer ring header.

Inside the radiation hood a water-cooled cone made of boiler tube was connected with the inner ring header. The non-cooled part of the outer hood was protected against radiation by panels in gapped pipe construction suspended in the annular area between the cone and the radiation hood.

Through this design the space inside the hood was subdivided into two separate chambers for indirect sucking of the ladle centre and direct sucking of the ladle near the rim. The ladle hoods were connected to the suction pipe by non-cooled fume hoods arranged on the roof of the ladle hood.

A water-cooled central part – the inside of which was made of refractory material – three water-cooled pneumatic slide gates for the lance openings as well as a water-cooled alloying funnel and a connecting piece for cored wire feeding were also connected with the ladle cover.

Limits of the existing system

Since commissioning of the ladle furnace, there have been growing signs of the fact that the ladle hood design was not optimal for the prevailing operating conditions. Especially the requirement of high plant availability was not fulfilled due to the high cleaning and maintenance effort required by the ladle hoods. Other problems arose from structural damage to supporting members of the construction.

The tubular construction of the outer radiation hood was highly susceptible to adhering slag, especially at the rectangular pockets covering the lifting bail. The slag had to be removed at short intervals at considerable effort. The removal was extremely difficult because of the rectangular form of the pockets with difficult-to-reach corners and large surface areas. This effect was additionally aggravated by the fact that the cross section of the cooling pipes was too large, resulting in correspondingly large undercuts and gaps between the pipes.

The panels suspended as radiation shields between the inner cone and the outer hood showed similar problems. The gapped pipe construction required for sucking the ladle at the rim was clogged by slag in a very short time. A satisfactory suction result was only achieved by means of a very high maintenance effort.

Also the water-cooled slide gates for the lance openings frequently failed. The gates of a rectangular tubular construction were pneumatically slid open and closed inside a frame made of steel plate. Due to the high thermal load, the frame was often heavily distorted, often making pneumatic operation impossible. An additional problem was that slag easily adhered to the bottom side of the tubular construction. A third problem only occurred with advancing service life of the ladle hoods, namely the insufficient static load-bearing capacity of the structure. The ladle hoods were suspended from the hydraulically actuated lifting column with a protruding console acting as a jib. The massive console was supported by both the ring-shaped headers of the hood and the outer radiation hood, which was partly made of steel plate.

The combination of the ladle hood's dead weight of approx. 20 t and the thermal load acting on the radiation hood resulted in plastic deformation of the steel plate structure. The ladle hood increasingly inclined towards the ladle. After a while the hood could only be moved into the treatment position after major adjustments had been made to the lifting system.

Figure 1. Water-cooled ladle hood

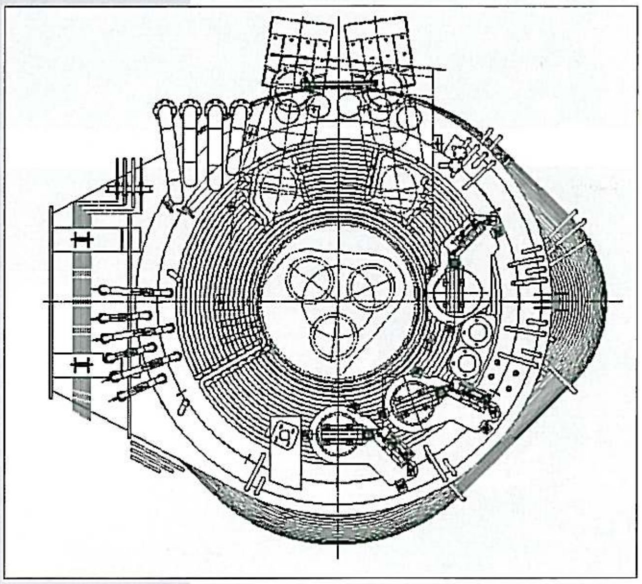

Figure 2. Drawing of the ladle hood (top view)

Objective of the modernization

At the end of 2001 ThyssenKrupp Steel AG decided to have the ladle hoods of both treatment stations redesigned. The order for the engineering, delivery and installation of equipment for both hoods was placed with KSK Kuhlmann-System-Kühltechnik, Haltern am See, Germany.

From the very start of the planning phase, there was an intensive dialogue between KSK and ThyssenKrupp Steel. The operator shared its experience with the operation of the existing hoods with KSK to enable consideration of operating experience in all phases of the engineering work. Complementing the existing drawings, KSK also performed comprehensive on-site measurements to obtain a clear view of the overall plant situation. On this basis the objectives of the modernization were defined.

Generally, the new hoods were to be less prone to failure and easier to clean than their predecessors. Additionally, the intervals between necessary maintenance work were to be maximized. According to the design concept, the geometry and the cooling tube cross


Figure 3. Layout of the old radiation hood

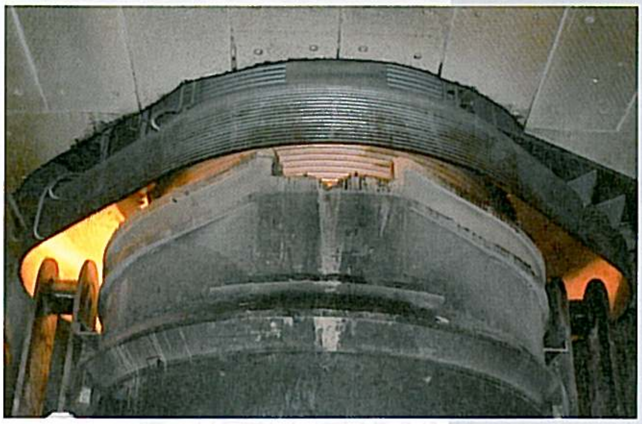
Figure 4. Layout of the new radiation hood

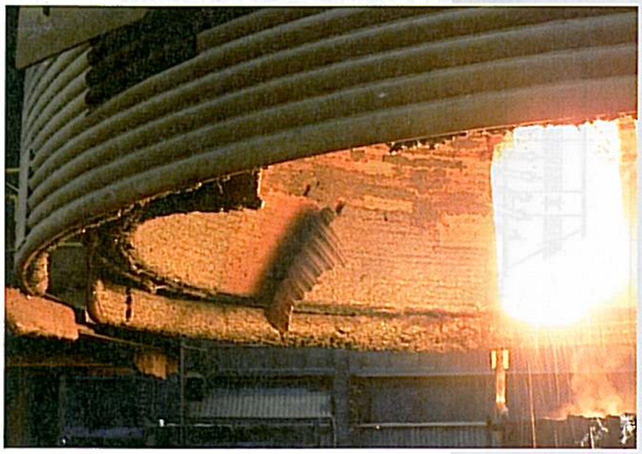
Figure 5. Self-cleaning radiation hood

sections of the outer radiation hood were to be modified with a view to avoiding adhering slag and facilitating cleaning.

It was concluded that the total hood unit was to be equipped with water cooling in order to prevent the hoods

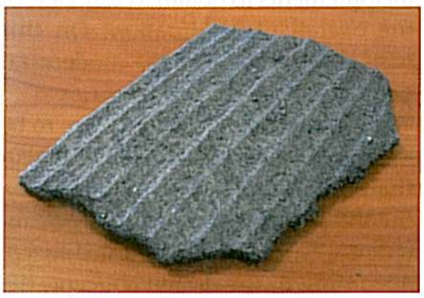
Figure 6. Peeled-off slag layer

from distorting due to the thermal load. At the same time the total weight of the hoods was to be decreased as much as possible. Another weak point of the existing equipment was the construction of the slide gates for the lance openings. Due to the extreme operating conditions and the non-cooled guide frame, the service life of the equipment was very short in the past. The problem was to be solved by redesigning the guiding mechanism of the gates.

In connection with the suction system it was decided to basically retain the principle of indirect ladle centre suction and direct periphery suction. However, the system was to be modified such that the suction of the zone near the ladle rim was to work reliably without the previously necessary cleaning of the ring channel.

A further requirement was to integrate the hoods into the existing furnace technology. This included retention of the existing transfer points on the lifting column and in the suction pipe as well as the position of the openings for the lances and alloy additions.

Conception of the new ladle covers

The design work for the new hoods started in early 2002, taking into consideration the experience with the old hoods and a number of specific customer requirements. Based on its longstanding know-how in the design and assembly of water-cooled components for steel plants, Kuhlmann-System-Kühltechnik GmbH conceived an innovative solution in line with the customer's requirements **(figures 1 and 2)**.

The outer radiation hood. The radiation hood was to be redesigned in such a way that the extreme accumulations of adhering slag, especially at the pockets covering the ladle lifting bail, are avoided in future. In addition to this, cleaning of the radiation side was to be facilitated and optimized by making it easier to reach and extending the maintenance intervals.

The rectangular shape of the pockets and the cooling element structure made of horizontal and vertical tube fields made the equipment susceptible to adhering slag due to the large surface area in the rectangular bends and in the corners. Also the large tube cross section results in wide gaps between the tubes and hence undesired proneness to adhering slag splashes in hood areas close to the slag.

For the solution of this task KSK GmbH realized a design concept that had already proven successful in another application. The structure of the new radiation hood consists entirely of rolled ring tubes, completely avoiding corners and undercuts. The pockets for the ladle lifting bail were integrated into this geometry by tangentially shaped transitions. The right angle in the cross section of the hood body was rounded along its complete circumference **(figures 3 and 4)**. Thus the problematic cornered parts of the hood are transferred into a homogenous geometry.

Moreover, for the lower hood part a smaller tube cross section was chosen. The gaps between the tubes were closed by welding in rounds to obtain a smooth hood surface. This very time-consuming manufacturing process considerably improves the cleaning situation on the radiation side.

Despite of this smooth surface, slag splashing during ladle treatment initially adheres to the cooling element and solidifies. Due to the cooling effect of the tubes and the radiation from the steel ladle, there is a strong temperature gradient in the adhering slag. After completion of the ladle treatment also the slag surface on the radiation side cools down. This causes thermal stress inside the slag. Similar to metal sheet heated on one side, the slag curves away from the hood surface, breaks up and cracks off in large pieces **(figures 5 and 6)**.

Suction system. With the first-generation ladle hoods, sucking the peripheral zone of the ladle turned out to be problematic in practical operation. The gapped pipe construction of the suspended panels serving as radiation shields clogged easily with slag. To solve this problem also the cylindrical hood was designed as a water-cooled structure. In this way the radiation shields could be dispensed with **(figure 7)**.

This design produces a ring-shaped channel between the outer hood and the inner cone for sucking the area at the ladle rim. The fumes arising at the ladle rim are sucked into the annular channel through an eccentrically arranged annular gap between the cone and the radiation hood. Five openings in the upper part of the annular channel are directly connected with the suction system of the plant via the fume hood. Maintenance doors are provided along the circumference of the hood for convenient cleaning of the annular channel.

The performance of the existing suction system in the ladle centre was generally rated as good. Therefore the principle of indirect suction was retained in the new hood design. In the new ladle hoods two circumferential ring headers are sealed towards the top by a flat cover made of boiler pipe.

A water-cooled cone in tubular construction is arranged above the central part of the ladle. Due to the thermal lift the hot fumes collect inside the cone and escape through the electrode opening of the refractory centre piece. Above the ladle hood the off-gas is fed into the suction system via a fume hood with open suction mounted on top of the ladle hood.

For the metallurgical treatment any influences of the ambient air on the steel bath are undesired. A process technological requirement therefore is to produce slight overpressure inside the ladle hood. This requirement is fulfilled in the new layout by the principle of indirect suction in the ladle centre.

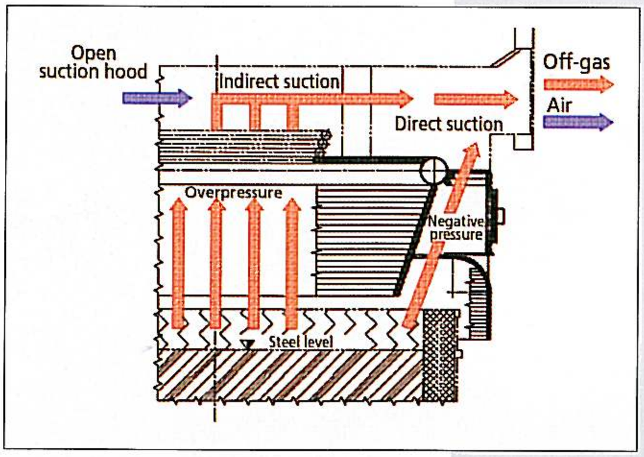

Figure 7. Ladle suction system (schematic drawing)

Figure 8. Water-cooled door

Static layout. With advancing service life, it became clear that the static strength of the structure was insufficient for the dead weight and other acting loads, including the thermal load on the non-cooled parts of the hoods. This resulted in plastic deformations of the outer hood and of the lifting console.

One approach to solve this problem was to reduce weight as much as possible through the use of smaller pipe cross sections. This measure reduced the manufacturing weight of the hoods from 20 t to 16 t. Thermal deformation no longer occurs thanks to the fact that all components of the hoods are water-cooled now.

The tong-type central lifting console is connected with both the ring header and the radiation hood. The static layout of the console was checked and reinforced by additional web plates. With a view to the enormous loads acting on the console the used plate material and the supporting welds were subjected to ultrasonic inspection.

Door design. In the original design the lance openings were closed by pneumatically actuated water-cooled slide gates. Problematic were above all the non-cooled guide frames which due to the heavy thermal load easily distorted, causing the slide gates to get stuck. The problem was additionally aggravated by slag adhering to the radiation side of gates.

An important limitation for the new design was the available construction

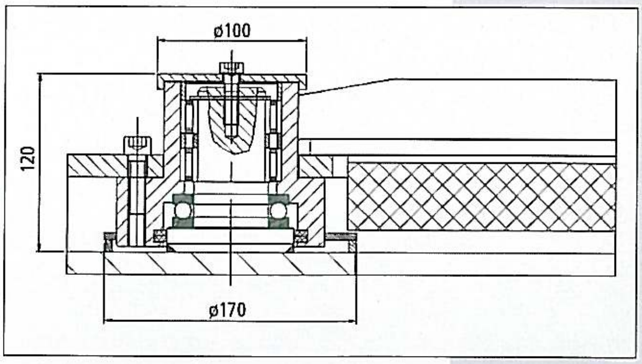

Figure 9. Improved bearing arrangement for the doors

Figure 10. Water-cooled fume hood

height, which was determined by the position of the lances. This is why the otherwise common flap doors could not be used in this case. This problem was solved by developing a swivelling mechanism for the new layout **(figure 8)**.

The cooling elements of the doors are eccentrically mounted on a vertical swivelling axis. For opening and closing, the doors are swivelled through 90°. As bearing solution maintenance-free sliding bearings with bronze bushings were used. The door is actuated pneumatically via a lever arm. The door position is controlled by mechanical limit switches.

To avoid adhering slag, a smaller pipe cross section was chosen for the cooling elements of the doors. The gaps between the pipes were additionally closed by welding in rounds. Like with the radiation hood, the self-cleaning effect of this flattened surface provided a satisfactory solution to the problem.

Continuous improvement

Installation of the first new ladle hood at treatment station No. 2 took place in the middle of 2003. Commissioning and the test run were successful and provided the expected results. After that the new hood was intensively tested during operation to identify additional potential for improvement. KSK GmbH actively participated in the test phase and the evaluation of the results.

The tests showed that the new hoods cope very well with the extreme operating conditions at the ladle furnace. The key requirements of the customer, i. e. markedly reduced maintenance costs and higher plant availability, have been met. Potential for improvement was identified for the door bearing solution.

The sliding bearings of the swivelling doors worked well at the beginning. However, after a while they showed signs of wear and they were increasingly difficult to move, as a result of the very high mechanical and thermal loads and arising dust. As a solution, the design of the door bearing was completely revised **(figure 9)**.

The revised roller bearing solution consisted of two needle bearings to accommodate the radial forces and one axial bearing for the vertical loads. To protect the bearings against the negative effects of dust and cooling water, they are now encased and filled with a permanent lubricant.

Operating experience has shown that the long service life of this solution justifies the relatively high mechanical effort involved in this bearing arrangement.

It was originally intended to continue to use the existing non-cooled fume hoods made of stainless steel. This solution, however, did not prove ideal because the non-cooled plate construction deformed due to the radiation from the electrodes. Another drawback was the cost of manufacturing the new components. Against this background ThyssenKrupp Steel decided in favour of a new hood design **(figure 10)**.

In 2004 Kuhlmann-System-Kühltechnik designed and manufactured the fume hoods as a water-cooled tubular construction. The design had to meet two requirements: the previous dimensions had to be retained and the fume hoods had to be integrated into the cooling water cycle of the ladle hoods.

As the fume hoods are subjected to relatively low thermal loads, the cooling water distribution could even be realized in a serial arrangement according the design of the fume hoods which consist of a front and a back part. Thanks to the arrangement in series the amount of cooling water required for the fume hoods could be halved. The resulting doubling of pressure loss was accepted because sufficient pumping capacity was available.

Operating results since commissioning of the cooled fume hoods in 2004 have been very convincing. Occasional cleaning of the hoods is the only maintenance required. As cooling has always been sufficient, the fume hoods have not required any repairs since their commissioning.

Conclusion

The new ladle hood for treatment station No. 2 was installed in 2003. The hood for treatment station No. 1 was installed in summer 2005. In the meantime both stations have additionally been equipped with water-cooled fume hoods. Operating experience with the new hoods has shown that the design solution will provide successful results also in the long term.

Both the effort and cost of maintenance required by the new ladle hoods could be markedly reduced. Extended maintenance intervals for the ladle hoods increased the availability of the overall plant. ■