

Stress Testing and Analysis of Self-adjusting Bolt in Converter

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Abstract: Oxygen top-blow converter is the main equipment in steelmaking. Because the support system of converter bears total weight of the converter and its accessories, and meanwhile transfers tilting torque from tilting mechanism to converter, it is the most important part of converter machinery. The joint equipment which links the converter with the support ring is the key part in the support system, and its work reliability decides the security and economy of steel production. The joint equipment of self-adjust bolt has the advantages of heavy-load bear capacity and simple structure, so it's the most important part of converter machinery. From the field testing, a large shock takes when the converter starting or breaking. Once the converter is broken at 63°, the self-adjusting bolts are under a large load and dynamic impact. So it will cause great instantaneous stress and a serious shortage of stress intensity reserves, the crack sources easily come up in the region of stress concentration and dangerous section. Analysis of steel-making process on all typical operating conditions, such as temperature detecting, sampling and slag tapping, the stress at 75° is close to the theoretical maximum stress caused at 63°, so the converter angle should be strictly controlled to avoid converter's braking at 63° and limit the residence time. At the same time the auxiliary converter connection (such as clamping, etc.) should be strengthened to ensure the safety factor. Finally some optimization measures should be made to increase the reserve strength and fully meet the production requirements. *Copyright © 2013 IFSA*

Keywords: Converter, Self-adjusting Bolt, Stress Testing, Stress Analysis.

1. Introduction

Oxygen top-blow converter is the main equipment in steelmaking. Because the support system of converter bears total weight of the converter and its accessories, and meanwhile transfers tilting torque from tilting mechanism to converter, it is the most important part of converter machinery [1, 2]. The joint equipment which links the converter with the support ring is the key part in the support system. The spherical hinge support joint equipment is used in No. 3 Steelmaking Plant of Shaoguan Iron & Steel Co. Ltd's support system of converter. The spherical

hinge support connects the converter and the support ring. This is the main bearing member of converter. And its work reliability decides the security and economy of steel production.

This paper study the self-adjusting bolt and test the field stress-strain in the typical operating conditions to fully and accurately grasp under load conditions and operating status of the self-adjusting bolts. Meanwhile, the actual measured data can be compared with the theoretical calculating results. It makes great sense to analysis the subsequent failure and optimally design.

2. A Brief Analysis of Strain Measurement Method

Resistance strain measuring method is the method that the strain is converted into an electrical signal for measuring [3]. It is called electrical measuring method for short. The basic principle is that the resistance strain gauge used as sensing element is firmly affixed to the surface measuring point of tested component. When the component deformed, strain gauge will deform together with the component. The resistance of the strain gauge will change accordingly. Changes in the resistance of strain gauges can be measured by resistance strain measuring instruments and then converted into quantity of chain or output analog signal (Voltage or Current) which is proportional to the strain and record with the recorder. The course of their work is shown in Fig. 1.

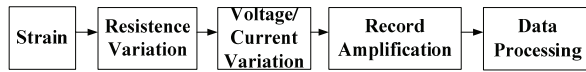


Fig. 1. Diagram of working process.

The relations between strain and resistance change of resistance strain gauge is that

$$\frac{\Delta R}{R} = K \varepsilon, \quad (1)$$

where R is the resistance value of the strain gauge, K is the strain gauge sensitivity coefficient and ε is the strain.

In the plan stress test, the measuring method will be taken according to the different arrangements of strain gauges and electric bridge combination type

1) Principal stress direction remains known. For uniaxial stress state, pasting a resistance strain gauge at the measuring point along the principal stress direction, measuring strain ε with resistance strain gauges. The principle stress of the measuring point can be obtained according to the one-way Hooke's law:

$$\sigma = E \varepsilon, \quad (2)$$

where E is the elastic modulus of measured material.

In the state of tension stress, strain gauges are usually pasted at the measuring point along two mutually perpendicular principal stress directions. Two principal stresses are calculated as follows after measuring the principal strain ε_1 and ε_2 :

$$\begin{aligned} \sigma_1 &= \frac{E}{1-\gamma^2} (\varepsilon_1 + \gamma \varepsilon_2) \\ \sigma_2 &= \frac{E}{1-\gamma^2} (\varepsilon_2 + \gamma \varepsilon_1) \end{aligned} \quad (3)$$

where E is the elastic modulus of measured material, γ is the Poisson ratio of measured material.

When the electric bridge combination type is half-bridge, the electrical bridge method shown in Fig. 2. In the state of uniaxial stress, R_1 is the work piece, R_2 for compensation sheet. In the state biaxial stress, R_1 and R_2 are the work piece, temperature compensation sheet should be set additionally.

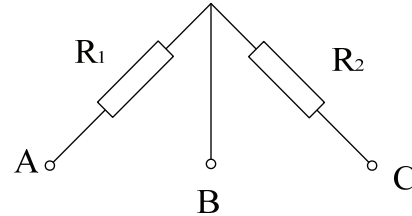


Fig. 2. Schematic diagram of half-bridge electrical bridge connecting method.

2) Principal stress direction remains unknown. In general, the measuring method is pasting strain rosette. We could calculate the magnitude and direction of the principal stress after measuring strain in three directions. The strain rosette is composed of three or more strain gauges arranged at an angle. We can use it to measure the strain in three directions and then calculate the magnitude and direction of the principal stress. There are rectangular-shaped strain rosette, equilateral triangle strain rosette, $T - \Delta$ strain rosette and double rectangular strain rosette in common. There are a variety of complex pattern strain rosettes supplied by the current market. We can select according to various working conditions and testing requirements.

Take the 45° strain rosette for example, we can calculate principal stress magnitude and direction of the component measuring points according to Equation 4.

$$\begin{aligned} \left. \begin{aligned} \sigma_1 \\ \sigma_2 \end{aligned} \right\} &= \frac{E}{2} \left[\frac{1}{1-\nu} (\varepsilon_{45^\circ} + \varepsilon_{-45^\circ}) \pm \right. \\ &\left. \pm \frac{\sqrt{2}}{1+\nu} \sqrt{(\varepsilon_{0^\circ} - \varepsilon_{-45^\circ})^2 + (\varepsilon_{45^\circ} - \varepsilon_{0^\circ})^2} \right], \quad (4) \\ \tan 2\alpha_0 &= \frac{\varepsilon_{45^\circ} - \varepsilon_{-45^\circ}}{2\varepsilon_{0^\circ} - \varepsilon_{45^\circ} - \varepsilon_{-45^\circ}} \end{aligned}$$

where ν is the Poisson ratio, E is the elastic modulus, α_0 is the angle between σ_1 and the 0° axis.

The combination of electrical bridge type is half-bridge or full-bridge. The methods of connection of electrical bridge are shown in Fig. 3.

In the Field testing, all kinds of errors should be eliminated as much as possible to improve the accuracy of the test [4]. The test mainly uses the following measures.

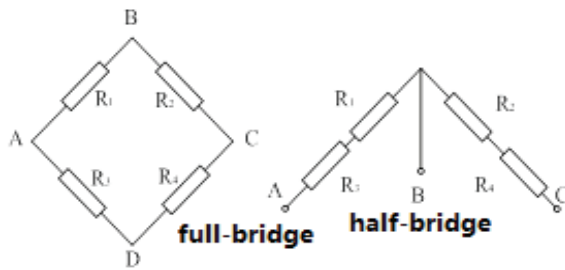


Fig. 3. Schematic diagram of biaxial stress electric bridge connecting method.

Select the appropriate instrument and calibrate accurately. We could improve the measurement accuracy by means of calibrating for the entire test system, measuring sensitivity and calibrating curve before the measurement, determining the relationship between the electrical output of the test system and the mechanical input with the standard quantity, calibrating the entire test system in the field testing.

Temperature compensation. During the testing period, the changes testing environmental temperature will cause that the member and the strain gages produce deformation temperature. The temperature change of strain gauge is not necessarily the same. The measured strain value will contains the influence of temperature variation, which will lead to measuring error. In order to eliminate measuring errors caused by temperature changes, the measurements use an electrical bridge compensation method to eliminate measurement errors due to temperature changes. It use the feature that adjacent electrical bridge arms generate the same size, the same sign as the resistance increment does not destroy the bridge balance to achieve the purpose of compensation.

Eliminating impact caused by wire resistance. Sensitivity could be amended.

Reduce erratic data. The specific method is making the electrical capacitance as symmetrical as possible, using shielded wire and grounding, in order to avoid the change of the distributed capacitance caused by the wires jittering. We should guarantee that resistance of the piece of work and compensation sheet are equal as far as possible.

Reduce patch error. When measuring one-way contingency, the deviation that the axis direction of the strain gages and the direction of principle strain will produce measuring errors. So full attention should be given when pasting the strain gauge.

The consistency of actual working conditions and rated conditions of the strain gauge should be guaranteed as far as possible. The difference of specimen material and the material being tested, meanwhile, the difference between nominal resistance value of Strain gauge and the bridge arm resistance of strain gauge will both cause errors.

Exclude electromagnetic interference of measuring field. The jittering of display value of measurement instrument mostly caused by

electromagnetic interference, such as poor grounding, the mutual inductance between conductors, leakage, electrostatic induction. We Should take appropriate measures to eliminate interference.

3. The Structure of Joint Equipment of Self-adjusting Bolt

Converter is supported on the support ring by the joint equipment. Converter tilt with support ring $\pm 180^\circ$ by joint equipment And the furnace shell and support ring will deform in the role of mechanical and thermal load. Therefore, the following factors must be taken into account in the design of support ring joint equipment. On one hand, the converter can be securely fixed on the support ring; on the other hand, it can adapt to the radial and axial relative displacement caused by the thermal expansion of the furnace shell and support ring in order to avoid the severe deformation and failure of furnace shell or support ring.

Additionally, accompanied by the deformation of the furnace shell and the supporting ring will caused the re-distribution of transferring load in the joint equipment, often resulting in partial overload, and thereby cause severe deformation and destruction. Therefore, the designed joint equipment generally has the following properties.

We ensure that the converter can delivery the furnace load to the support ring when it is in the upright and tilting position. The text should be typed double-spaced and justified and maintain the correct position of the converter in the support ring.

We ensure that it is able to adapt to the expansion and contraction of converter in the axial and radial directions without motion.

The converter load is evenly distributed in the support ring. The influence on the strength and deformation of the furnace shell is reduced to a minimum Use.

Taking the deformation into account, load can be transferred in a pre-determined manner. And we should avoid that the support system bear the additional load due to the existence of statically indeterminate problems.

The structure is simple and reliable. And it can slow down the dynamic load and impact. Joint equipment should be installed and adjusted easily, meanwhile, it should be easily maintained.

It is usually difficult to take all the above points into account. Generally, we should preferentially consider the previous requirements in accordance with the order.

As shown in Fig. 4, configuration of three sets of spherical hinge support is 120° . The lower is connected by pin and bearing seat on the support ring. It can arbitrarily swing on the pin. The upper is connected by snap ring through the two spherical washer and the annular spring washer nut locked by nut. It can swing within a narrow range along the

radial direction of the converter relying on spherical hinge support. Three groups of spherical hinge support joint equipment bear the weight of the converter.

“Three-point support” structure of self-adjusting bolts joint equipment on the support ring is used. One point is in the opposite side of taphole. The other two points located on both sides of the taphole. Three points spaced from each other by 120°. It is Shown in Fig. 5. The components of apparatus are shown in Fig. 6. It Mainly include the stop plate, dust cover,

spherical nut, ring springs, upper spherical mat group, lower spherical pad group, self-adjusting bolt body, horizontal pin and other parts. The upper and lower spherical pad group respectively mounted on the top and bottom of the converter flange. It should be lubricated once with molybdenum grease on the spherical surface where it generates a relative movement in the installation. The two bracket supported the horizontal pin are welded to the support ring.

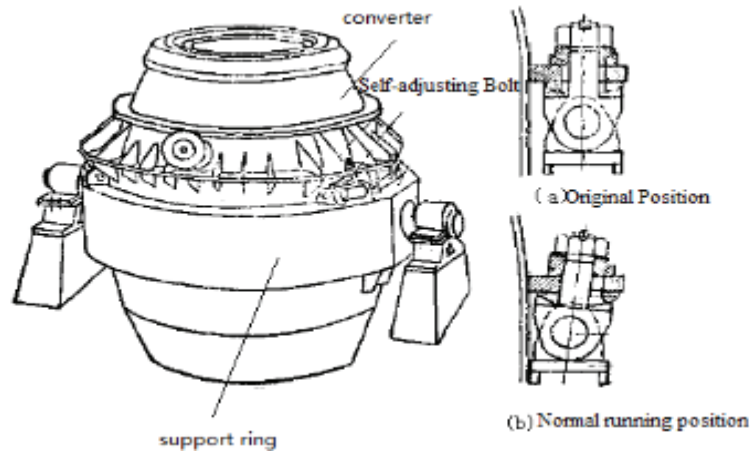


Fig. 4. The joint equipment of spherical hinge supporting.

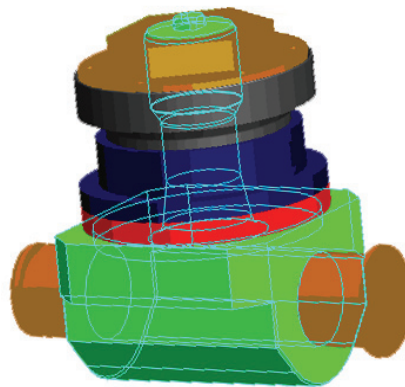


Fig. 5. Entity model diagram of the joint equipment of Self-adjusting Bolt.

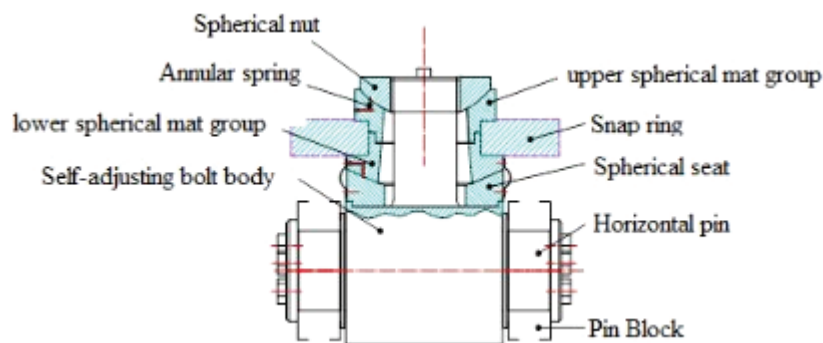


Fig. 6. Structure and composition of Self-adjusting Bolt.

The lower part of the device is connected to the bearing of the support ring through the pin. It can arbitrarily swing on the pin. The upper part of the device is connected to the snap ring. It is locked with nut by the two spherical gaskets and annular spring washer, swinging along the radial direction of the converter relying on spherical self-adjusting bolt.

The number of three-point supporting is smaller. 300 ton capacity of the converter is only three. The structure is very simple, as well as the manufacturing and installation. They have higher requirements on the material because of its load of three-point support, of which self-adjusting bolt body (loose bolt), horizontal pin, nut and spherical washers need to use high-quality materials.

The converter with clamp structure to withstand the load of plane direction which parallel to support ring and limit the furnace body to rotate in supporting ring. It is shown in Fig. 7. Long trunnion upper gripper and short trunnion upper gripper is fitted with above the converter. Two trunnion lower gripper and four auxiliary gripper symmetrically distributed with the trunnion 35° is equipped with the below of the support ring. The bracket of converter clasp is embedded within the groove of the support ring and contact only on the side with the gripper groove to restrict lateral displacement of the converter and bear load in a direction parallel to the plane support ring.

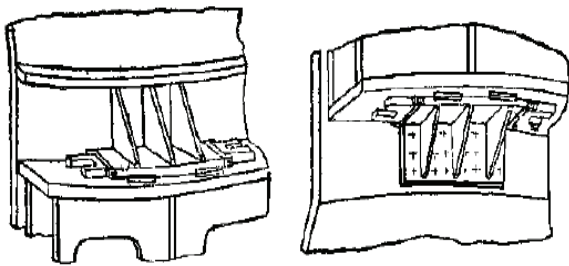


Fig. 7. Structure diagram of the upper and lower gripper.

4. Field Test Methods and Programs of Self-adjusting Bolt

4.1. Scheme of Strain Gauge Arrangement and Measuring Points

It shows that the taphole contralateral self-adjusting bolt only bear the axial tension and compression stress along the body of the bolt when the converter tilting from front self-adjusting bolt load analysis. That is in the uniaxial stress state. Therefore, in this test, the strain gauge arrangement method is shown in Fig. 8. The electrical bridge method is shown in Fig. 2, where R_1 is the work piece, R_2 for compensation sheet. According to the theoretical analysis, simulation results, objective

factors such as the live production environment, strain the piece measuring point is in the middle of bolt body of self-adjusting bolt. It is about 360 mm from measuring point to the top of the bolt body.

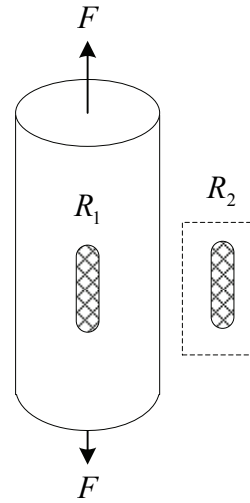


Fig. 8. Schematic diagram of patch.

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, IFSA, ac, dc, ms, etc. do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

4.2. The Composition of the Test System

The field test system is shown in Fig. 9. Point measuring signal is collected by the data acquisition module by the strain conditioner and transferred to the laptop through the 1394 card, real-time data processed and analyses by using signal processing software; meanwhile, measuring and recording real-time signal of converter tilting so that it can better reflect the relationship of the converter position and the stress change of self-adjusting bolt.

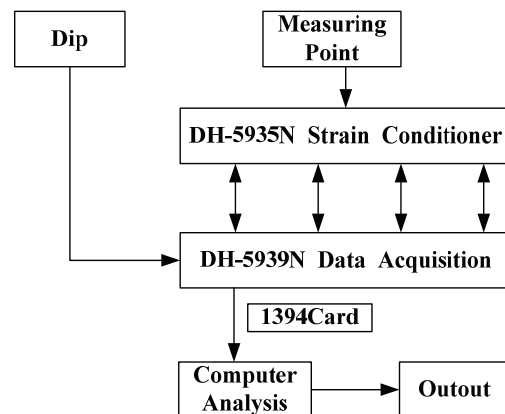


Fig. 9. Block diagram of the test system.

4.3. The Test of Working Condition

With the cycling of empty converter→adding scrap metal→adding molten iron→steelmaking→deslag→tapping, the load Self-adjusting bolt cycle with the course of steelmaking time history. So this test is to be measured and recorded for a whole working conditions of steelmaking. Each of the major conditions and the corresponding angle are shown in Table 1.

Seen from the working condition testing table, the main angle position of converter in a whole steelmaking working conditions corner are about 45° of empty converter, upright of full converter, about 70° of full converter, from 90° to 120° of full converter. With the number of difference of types of steel and times of the actual temperature sampling, the converter is in the position of about 63° about 4 to 6 times, and it always in the full converter state, self-adjusting bolt will bear greater cyclic loading. So this position should be paid more attention in testing.

Table 1. Working condition description of a whole working conditions and converter angle

Corresponding working conditions	Description of converter angle	Duration	Remark
Adding scrap metal, and hot metal charging	Rotated from the upright position to the 45° position	3 minutes	Empty converter, impact
Blowing	Upright position	15 minutes	Full converter
Temperature measurement, sampling	Rotation to 75°, come back to the upright position	3 minutes	Full converter
Reblowing	Upright position	3 minutes	Full converter
Deslag	Rotation to 75°	3 minutes	Full converter
Steel tapping	Back to the upright position, continue to rotate down to -120°	5.5 minutes	Full converter gradually change to the empty one
Pouring slag, slag splashing	Upright position rotated up to 180°		Empty converter

5. Results and Analysis Self-adjusting Bolt Stress Test

In the actual test, in an upright position when the converter is in the air furnace state, we do the work, such as strain gauge placement, wiring and system

installation and commission when the converter is the upright position of empty converter state. This situation is regarded as the zero test and calibrates the system. The test recorded a total of seven steelmaking processes. Each full working condition recording time is 2000 seconds, By de-noising and filtering processing of the strain signal, actual stress curve of measuring point in the each angular position of converter can be obtained according to the stress-strain conversion formula.

Converter inclination curve of one whole working condition is shown in Fig. 10, from which we can see that from the beginning converter rotated to about -75° to pour molten iron and add scrap then go back to an upright position to blow. This process is probably 16 minutes in 120 seconds to 1200 seconds.

Subsequently converter rotated to -75° to sample. After Sampling is completed then go to the upright position to reblow. Then rotate to about -75° to slag, finally rolled back to an upright position. And finally go back to the upright position. After 30 seconds, we continue the steel tapping until it is poured out. This process is within 1450 seconds to 1900 seconds for about 7 minutes. At last the converter has the rotation, such as empty converter pouring converter, slag splashing and other conditions.

The curve of stress variation of the measuring point in the vertical direction is shown in Fig. 11, the stress rangeability is in -13.05 MPa to 180.70 MPa, which respectively correspond to the converter upright position and 45° positions. When the converter is 63°, the variation stress is 123.5 MPa.

The stress distributions in the vertical direction of element 2 when the converter is 63° are shown in Fig. 12 and Fig. 13. This moment the support ring component force in horizontal direction led to drastic increase in the bolt body stress. The maximum stress reaches to 967.68 MPa which located in the middle of the bolt body. In the actual production, if the holder gap is too large, it will cause the converter does not work instantaneously. It means that three groups of self-adjusting bolt bear all the weight. The results of the contact analysis show that strength reserve is insufficient at this time. It is easy to cause internal cracks leading to fracture. Fracture location of the factory's two converter self-adjusting bolt is consistent with the theoretical analysis results.

Select a stress analysis of the three nodes of the measuring point and take the average value of the corresponding node stress statistical results and then compared with the field test results. The results are shown in Table 2.

According to comparative analysis of the test results and the finite element results. The trend of stress change in the measuring point is the same. The error is also in a narrow range, the results are in line with the actual situation. It also verifies the correctness of finite element model and the simulation method.

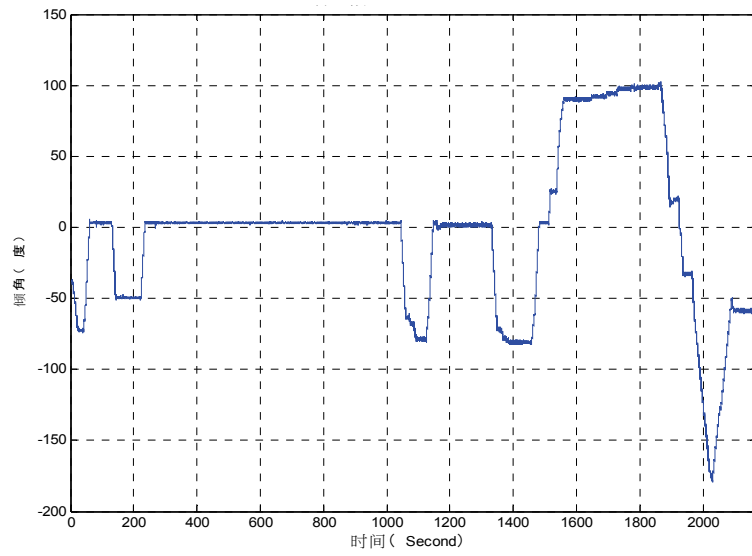


Fig. 10. Converter inclination curve of field testing of a whole working condition.

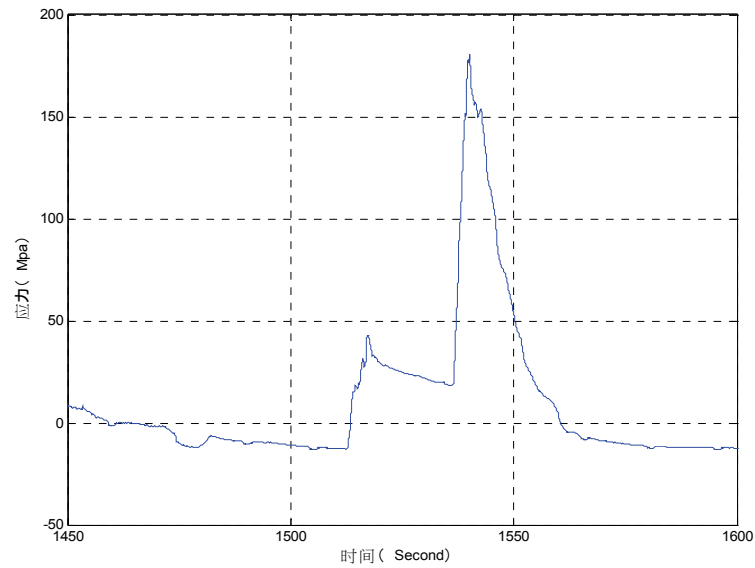


Fig. 11. Stress variation of the he measuring point in vertical direction (1450~1600 s).

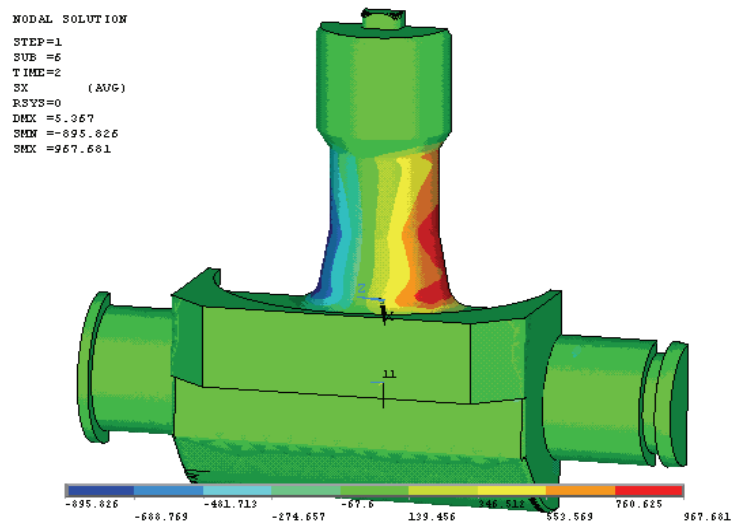


Fig. 12. Stress in vertical direction of element 2 when converter at 63°.

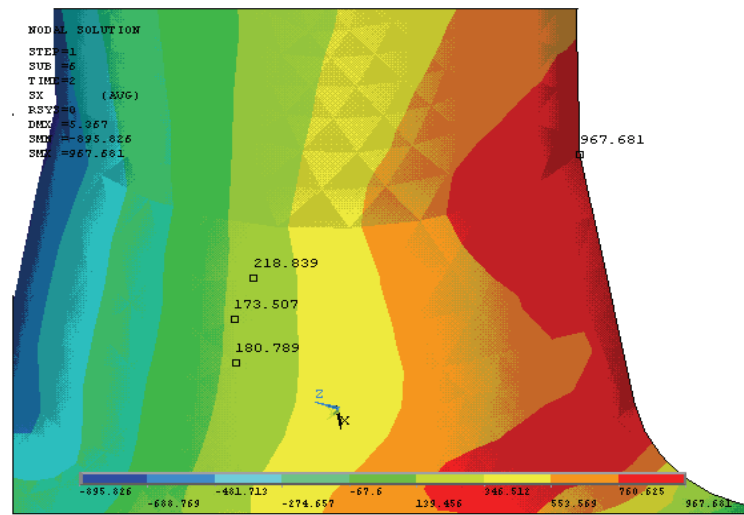


Fig. 13. Vertical Stress of element 2 measuring point when converter at 63°.

Table 2. Comparative statistics of field test and finite element computation results.

Working condition	The converter position rotated from 0° to 63° (MPa)
Variation of stress	
Field test result	136.55
Finite element computation result	134.862
Error	1.688

6. Self-adjusting Bolt Optimized Measures

Seen from field test, there is a big impact when the converter starts and barks. Self-adjusting bolt is larger load and then superimposed on the dynamic impact. It is easy to produce instantaneous stress resulting in a serious shortage of strength reserve and is likely to generate cracks produced in the areas of stress concentration and the dangerous section. Therefore, in the production process the converter angle should be strictly controlled and the role of joint equipment should be strengthened, such as gripper, to guarantee the safety factor.

The contact stress of screw pair is larger in the actual situation and the ends of screw tend to produce stress concentration. For example, from the quality of the processing, the position of variable cross-section rounded at the transition of the knife marks will generate fatigue cracks due to the severe stress concentration. Therefore, we should ensure the fitting accuracy of the self-adjusting bolt components and the appropriate clearance to reduce the impact of external shocks.

According to the testing condition, we could optimize the size of the larger stress position for the

self-adjusting bolt to reduce stress concentration. The measures such as increasing diameter of the bolt, getting greater fillet and taper are included.

Reasonable heat treatment process are used to improve the mechanical properties of self-adjusting bolt, such as carburizing, nitriding, shot peening, surface hardening treatment and other measures. They can improve the fatigue life.

7. Conclusions

Aiming at actual production, we test on-site stress-strain of the converter in the typical operating conditions and analyze the loading conditions and operating status of self-adjusting bolt. The analyzing results of measuring data are basically the same with finite element computing results. It verifies the correctness of the calculation model. Seen from field test, there is a big impact when the converter starts and barks. Once the converter is about 63° braked Self-adjusting bolt are larger load and then superimposed on the dynamic impact. It is easy to produce instantaneous stress resulting in a serious shortage of strength reserve and is likely to generate cracks produced in the areas of stress concentration and the dangerous section. By analyzing typical operating conditions of the steelmaking process, converter is usually about 75° which is closer to the theoretically maximum stress of the 63° position when measuring temperature, sampling, slag. So in the production process, we should strictly control converter angle and try to avoid braking in the 63° position and control the residence time. The role of joint equipment also should be strengthened, such as gripper, to guarantee the safety factor. After preliminary analysis and discussion, structure optimization measures are proposed to improve the security reserves to fully meet the production requirements.

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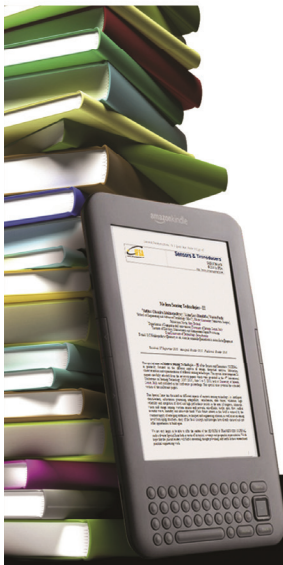
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