Discussion on the Optimal Scheme to Realize the Excellent Running Quality of the Converter

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Abstract: The running quality of the converter, especially the 100t ~ 500t medium and large converter, refers to the safety indicators such as no obvious wear, impact, vibration and abnormal noise, and the stable operation of the equipment, with sufficient safety margin and stability. In this paper, six typical under suspension support mechanisms which mainly used in various countries in the world today are described, and the characteristics of the under suspension supporting mechanism converter are analyzed from three aspects: components, number of suspension support mechanism and layout of suspension support mechanism. The stress and deformation of the support mechanism are analyzed by finite element method and verified by a large number of practical engineering. The research results show that the optimal choice of the hanging mechanism of the converter is to use the connecting rod mechanism; The optimal combination of the number of suspension mechanisms is four groups of vertical suspension mechanisms and four groups of horizontal support mechanisms. The optimal position of the suspension mechanism is that the horizontal support mechanism is located directly above the vertical suspension mechanism. If the above three are met, the running quality of the converter must be excellent, which also means the trend and direction of the development of the supporting technology of the converter in the future.

Keywords: Converter; Supporting Mechanism; Connecting Rod Mechanism; Running Quality

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1 Introduction

This paper focuses on the research and discussion of the converter support mechanism which mainly affects the running quality of the converter, especially the 100t ~ 500t medium and large converter (safety and whether there is wear, impact, vibration and abnormal noise, etc.) 1) the components of the hanging mechanism, 2) the number of the hanging mechanism, 3) the ideal and leading technology of the hanging mechanism layout. Through SMS/DANIELI, which is mainly adopted, popular, and still preserved and developed in the world today LAMELLE Plate Spring Connected Converter [7, 9-11], VAI CON-Link Five-link Supported Converter [6, 7, 12, 17, 18], Danieli Tie-rod Suspended with Dani-ella Supported Structure Converter [14, 15], MCC CISDI-SACS Four-point under Suspension Converter [3], Primetals Vaicon Link 2.0 Eight-link Hanging Converter [16] and MCC CISDI-SACS Eight-link Converter Technology [1] six typical hangling support mechanisms under the converter were analyzed and studied one by one and a lot of engineering verification was carried out, and the ideal and optimal engineering combination scheme of the support mechanism for the converter was obtained to ensure and achieve the excellent running quality of the converter.

2 Analysis of the Ideal and Innovation of Converter Support Technology

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A large number of engineering practices have proved that the key point that affects the operating quality of the undersuspension converter is the design of the horizontal supporting mechanism [1], therefore, the following research is mainly aimed at the horizontal supporting mechanism of the undersuspension system of the converter. Through the comprehensive analysis and research of typical converter supporting technology in the world today, it is concluded that the operating quality of the converter, especially the large converter, is mainly affected by three aspects: components, quantity, and layout of the suspension mechanism, and the following analysis, research, and demonstration are carried out from these three aspects to find out the corresponding optimal technical scheme.

2.1 Components of the Suspension Mechanism

The requirements of the connecting supporting mechanism components of the converter are as follows: it can not only meet the mechanical strength and rigidity of the connecting and supporting mechanism, but also adapt to the irregular thermal deformation of the converter vessel and trunnion ring without gap, so as to ensure the safety of the converter, and to ensure that there is no impact, vibration and abnormal sound.

The horizontal support structure technical schemes of the six typical converter lower suspension technologies mentioned before use two different types of suspension mechanism components, namely: block seat components and connecting rod mechanism components.

2.1.1 Block Seat Components

The working principle of the structure of the block seat equipment is: according to the working principle of the block seat, there must be a gap between the converter vessel block seat and the trunnion ring block seat, so that the contact surface of the trunnion ring can relatively slip to adapt to the thermal deformation between the converter vessel and the trunnion ring, and at the same time, the horizontal support and connection [4, 5, 7, 18] between the converter body and the trunnion ring ring can be realized.

The main advantages of the block seat components are: High strength and stiffness, and no thermal protection needed.

The main disadvantages of the block seat: the gap between the converter vessel block seat and the trunnion ring block seat will inevitably expand gradually during use, and the furnace must be regularly stopped for maintenance and replacement of worn parts during production. When the converter is running, with the gap between the holder and the ring holder gradually expanding, impact, vibration, wear, and abnormal sound will occur between the converter vessel block seat and the trunnion ring block seat, thus affecting the operating quality [1] of the converter.

2.1.2 Connecting Rod Mechanism Components

The working principle of the connecting rod mechanism equipment structure is as follows: both ends of the connecting rod mechanism are hinged with the furnace shell connecting rod seat and the trunnion ring connecting rod seat, and the joint bearings are hinged at both ends of the connecting rod, forming a universal pendulum rod to adapt to the thermal deformation between the converter vessel and the trunnion ring, and at the same time, the horizontal connection and support [6, 7, 12, 17, 18] between the converter body and the trunnion ring can be realized.

The main advantages of connecting rod components are: Local constraints of each connecting rod (Shaft support at each end of the connecting rod has a joint bearing); Ability to adapt to the ring and converter vessel thermal deformation without gap; Adaptive action ability; Two force rod structure leads to simple applied force and conducive to equipment manufacturing; No need to adjust; Not sensitive to the lack of grease lubrication environment; Theoretically the converter tilting operation will not produce impact and abnormal sound, longer working life; The equipment is maintenance-free [17, 18] for a long time.

The main disadvantages of connecting rod parts are: The need to use high-temperature resistant bearings and to design connecting rod mechanism thermal protection devices; Joint bearing equipment investment is relatively high [1].

2.1.3 Analysis of the Influence of Block Seat and Connecting Rod Components on the Operating Quality of the Converter

The converter vessel block seat and trunnion ring block seat parts are fixed on the converter vessel and trunnion ring respectively. There must be a gap between the two block seats to adapt to the thermal deformation of the converter vessel and trunnion ring. Once the gap increases, great impact, vibration, and abnormal sound will be generated, which will affect the running quality of the converter. To achieve good running quality of the converter, the gap shall be stable as far as possible. CISDI pre-stressed tie rod integral block seat technology [8] is fundamentally different from the technical effect of traditional separated block seat structures, which significantly improves the running quality of the converter. However, it is technically difficult to ensure the constant gap. Therefore, the source of the abnormal noise of the converter cannot be completely eradicated according to the operating principle attribute of the inherent equipment structure of the block seat system [4].

The rod seat of the connecting rod mechanism is fixed on the furnace shell and the trunnion ring respectively. The connection between both ends of the connecting rod and the rod seat is hinged with the joint bearing, which can ensure a stable connection and adapt to the thermal deformation of the converter vessel and the trunnion ring without clearance, to ensure the running quality of the converter. More importantly, when the mechanical strength and rigidity of the connecting rod meet the design requirements, it can ensure that there is no clearance, impact, vibration, or abnormal sound without adjustment, and it can maintain the maintenance-free operation for a long time, excellent and stable converter running quality [17, 18].

Therefore, it can be seen between the working principle of the mechanical structure of the block components and connecting rod mechanism components that the connecting rod mechanism is obviously superior to the block structure for ensuring the running quality of the converter.

2.1.4 Project Example

In 2012, a steel mill made the horizontal support for the No. 1 210t converter of the Jinan steel mill, which is located at the upper and lower part of each trunnion support block, and set main and auxiliary block seats at the support. After being put into production, the converter produced vibration, impact, and abnormal sound. After repeated adjustments and treatments, the block seat gap was still not completely solved. Later, with the horizontal support position remaining unchanged, The main block at the horizontal support position below the trunnion block was changed to a set of horizontal connecting rods, completely eliminating converter vibration, shock, and abnormal noise.

Through the analysis of the influence of the structure and working principle of the block seat parts and the connecting rod mechanism parts on the running quality of the converter and the actual engineering verification, it is concluded that the connecting rod mechanism parts are superior to the block seat parts to ensure the running quality of the converter.

2.2 Number of Suspension Mechanisms

The requirements for the design quantity of connecting and supporting mechanisms of the converter are as follows: each suspension mechanism bears a uniform load, meets the mechanical strength and rigidity of equipment required for horizontal connection and support of a large converter, and has sufficient equipment safety margin to ensure the running quality of the converter.

2.2.1 Project Example I

VAI-CONLink two-point horizontal suspension and three-point vertical suspension five-link suspension structure are adopted for 150t converter of a steel mill, which was completed and put into production in 2012. After the damage and replacement of horizontal suspension bearing of converter in January 2018, horizontal and vertical supporting connecting plates successively broke in December 2018, which had a great impact on the production of 150t converter [6, 13, 18].

Figure 1 The Scene Fracture Photo of Connecting Rod of Five-link Suspension Mechanism of 150t Converter of a Steel Mill

Finite element calculation and analysis on fracture of five-link suspension support connecting plate of a steel mill:

The nominal capacity of the converter is 150t, the average tapping capacity is 175t, the maximum tapping capacity is 185t, the average hot metal loading capacity is 186t, and the maximum loading capacity is 190t. The relevant design calculation is carried out in combination with the converter type drawing of a steel mill. Under the general working condition of converter, the weight of converter body is composed of the following parts: the weight of converter body is about 221.7t, and the weight of furnace lining is about 473.9t; Weight of gas and water piping of converter vessel: 4.6t; Slag sticking at furnace mouth: 15t; Hot metal, scrap, and slag is about 212.3t; The above weight is about 927.5t in total. Considering the dynamic load, the dynamic load coefficient is 1.1; As per 927.5 × 1.1≈ 1030t calculation of total load. Modeling the connecting ros based on the design drawing, the finite element calculation is carried out for vertical and horizontal connecting rods respectively. The analysis result of the stress and deformation are shown in Figure 2~Figure 5.

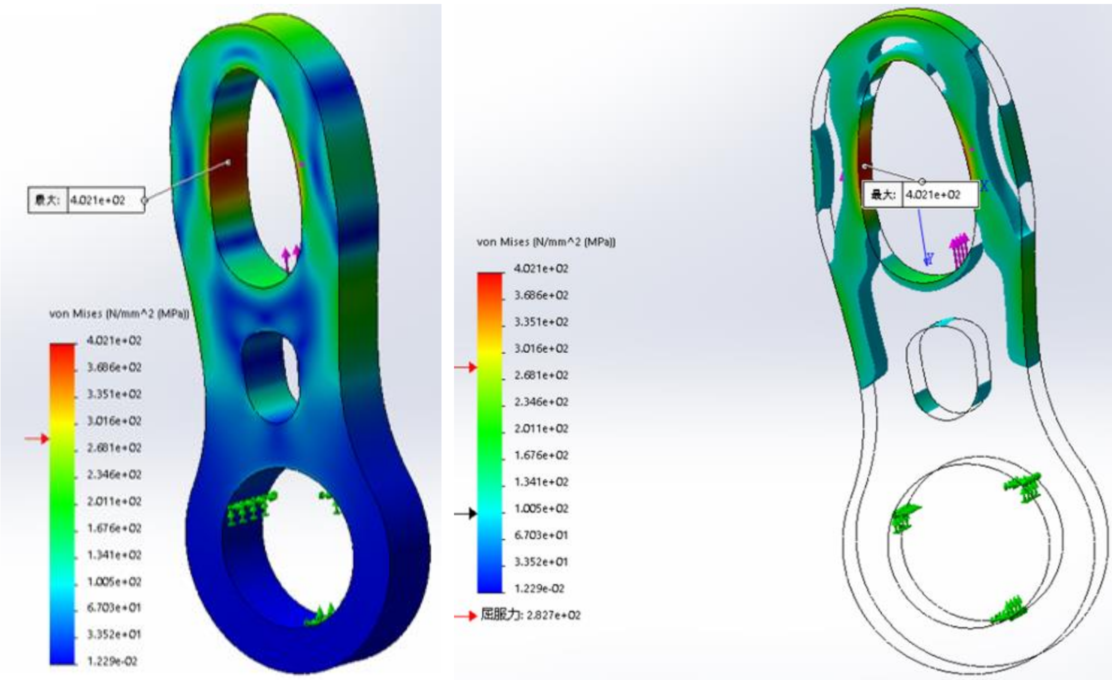

Figure 2 Stress Analysis Results of Vertical Tie Rod

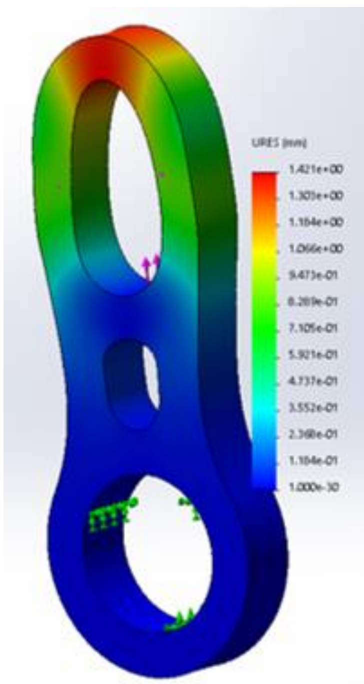

Figure 3 Deformation Analysis Results of Vertical Tie- Rod

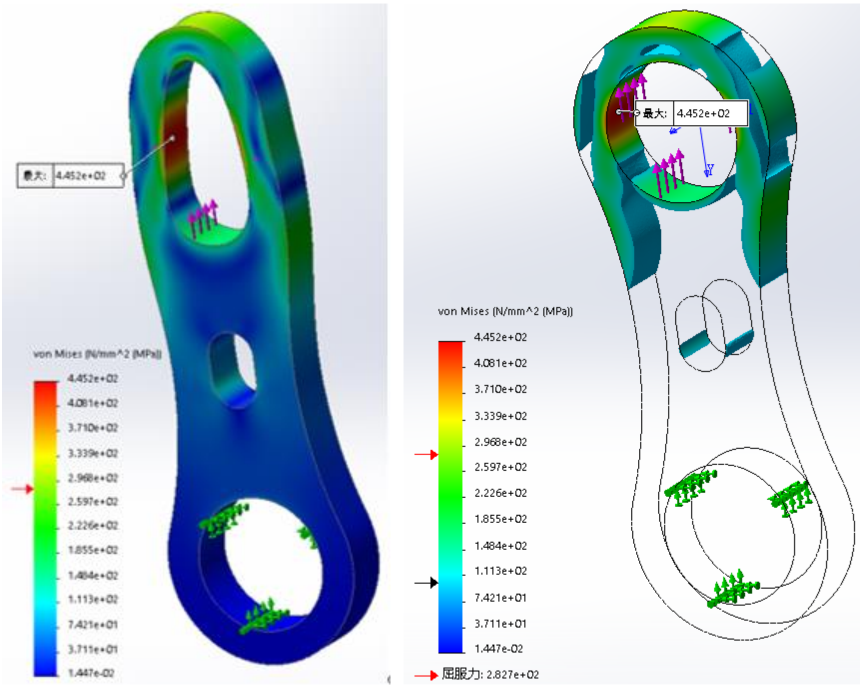

Figure 4 Stress Analysis Results of Horizontal Connecting Rod

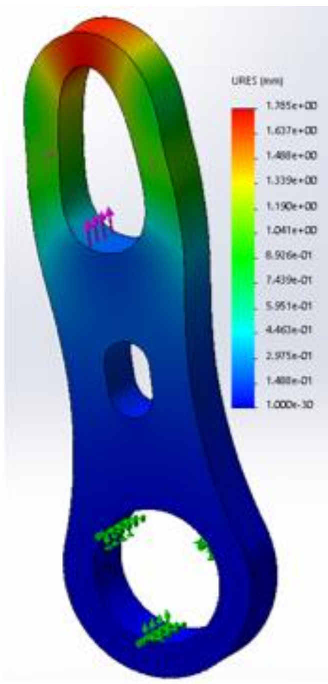

Figure 5 Deformation Analysis Results of Horizontal Connecting Rod

It can be seen from the finite element calculation and analysis diagram that the maximum stress of the vertical suspension mechanism is 402MPa, and the maximum stress of the horizontal suspension mechanism is 445.2MPa. The material of the pull rod is 30CrMo. According to the drawing, Rel ≥ 480MPa at 350 ℃, then:

The safety factor of the vertical pull rod stress ns=480/402 ≈ 1.19, and the safety factor of the horizontal pull rod stress n_s=480/45.2 ≈ 1.08.

The above calculation results show that the safety factor of the horizontal connecting rod and vertical tie rod supported by the five-link converter in the certain steel mill are 1.1 ~ 1.2, and the safety margin is insufficient (according to the Mechanical Design Manual and a large number of engineering practices of CISDI, the safety factor is generally at least 1.8-2.0), and the safety factor of the vertical tie rod supported by the three-link is less than 1.2. Especially when the converter tilts to the horizontal position of 90°, the safety factor of the horizontal connecting rod supported by two points is less than 1.1, and the safety margin is low. The maximum stress of the horizontal connecting rod at the fracture of the photo in Figure 4 reached 445.2MPa, and the maximum deformation is 1.785mm in Figure 5. This is related to the deterioration of the stress at the fracture position of the connecting rod when the joint bearing of the connecting rod fails and the bearing clearance is damaged, because the horizontal connecting rod breaked first at the maximum stress fracture greater than the material yield limit Rel, In an instant, the converter vessel produced a huge impact force on the trunnion ring, and the fracture position of the horizontal connecting rod and the fracture sequence of the horizontal and vertical connecting rod are consistent and consistent.

2.2.2 Project Example II

Primetals Technology Co., Ltd. has improved the five-link suspension technology of the Voestalpine CON-Link converter by csuspension 2 groups of horizontal swing rods into 4 groups and 3 groups of vertical connecting rods into 4 groups, finally forming the Primetal Technologies Vaison Link 2.0 Eight-link Converter Support Technology with 4 vertical suspension support links and 4 horizontal suspension support links, which was successfully applied to the 225t converter suspension reconstruction of AK Steel Plant, NJ in April 2021 [16].

The two engineering examples show that different numbers of vertical suspension and horizontal support groups play different roles and technical effects, which fully demonstrates the importance of setting the number of suspension groups.

Six typical lower suspension converter horizontal supports are provided with different support mechanism quantities. The total quantity of Lamalla, CON-Link and Tie-rod suspension horizontal supports is 2 groups, and the total quantity of the horizontal supports of Vaicon Link 2.0, CISDI-SACS four-point suspension, and CISDI-SACS eight-link is 4 groups. A lot of engineering practices have verified that, regardless of the type of suspension mechanism structure, as long as the total quantity of horizontal supports is designed as 2 groups, They can not meet the requirements of large converters on the mechanical strength and rigidity of horizontal support [2, 3, 6, 7, 17, 18]. The above specific engineering examples can verify the importance of the number of suspension mechanisms.

Through a large number of actual engineering verifications, to ensure the running quality of 100t~500t medium and large converters: using 4 groups of vertical suspension mechanisms and 4 groups of horizontal supporting mechanisms is the optimal scheme for the suspension quantity of medium and large converters.

2.3 Arrangement of Suspension Mechanism

The arrangement of the suspension mechanism is also closely related to the running quality of the converter, and a typical engineering example is also used as a verification:

The supporting position of the horizontal main block seat of the 250t converter of Baosteel Meigang designed by CISDI is located right below the trunnion support block on the two sides far away from the converter vessel before the transformation. As a result, the production site of the converter is: during the operation of the converter, there is a large abrasion and gap between the trunnion ring and the horizontal block seat of the converter vessel, resulting in strong impact and abnormal sound of the converter. The strong vibration can be obviously felt on the operating platform in front of the converter.

Through long-term research on the running quality of the converter supported by the block seat and the cause and mechanism of abnormal sound during the tilting process as well as finite element analysis and a lot of engineering practice verification, CISDI has gradually realized that at the position of the middle part of the converter trunnion support block, o matter whether the block seat is located on the upper or lower surface of the middle part of the support block, the alternating bending deformation between the trunnion ring and the converter vessel is the largest:

When the block seat is installed at this position, the "alternating elastic slip" (AES) between the block seat of the converter vessel and the trunnion ring block seat will be caused to become maximum. The AES is the key to affect the stable operation of the converter. The AES reflects the rigidity of a converter mechanical system [2, 3]. Due to the elasticity of the converter structure, under alternating load, the contact surface of the parts has a relative slip, and the actual working condition determines that the contact surface is blocked and the slip is not smooth [2, 3]. Such slip will cause the wear of the contact surface between the converter vessel and the trunnion ring block seat, so that the gap between the block seat gradually expands, resulting in converter impact, vibration, and abnormal sound.

If the connecting rod is installed at this position, the "alternating misalignment displacement" [1] (AMD) between the converter vessel and the trunnion ring will become maximum. Under alternating load, as the connecting rod mechanism cannot flexibly swing in the tilting plane, the movement of the converter vessel must overcome the constrained elastic deformation critical point. When the critical point is exceeded, the elastic energy will be released, and the contact surface of the parts has relative alternating misalignment displacement [1, 2], If the swing rod mechanism has the poor adaptive ability and insufficient strength and rigidity, the final result is that the joint bearing clearance of the swing rod is damaged under alternating impact load, the swing rod is no longer the working principle of the two-force rod, and finally the fatigue fracture of the swing rod will occur. Even if the swing rod is not broken, but because of the superposition of AMD and the working load of the swing rod equipment, the internal defects of the swing rod are continuously accumulated and expanded until the connecting plate is broken. It will bring serious risk to the equipment safety production.

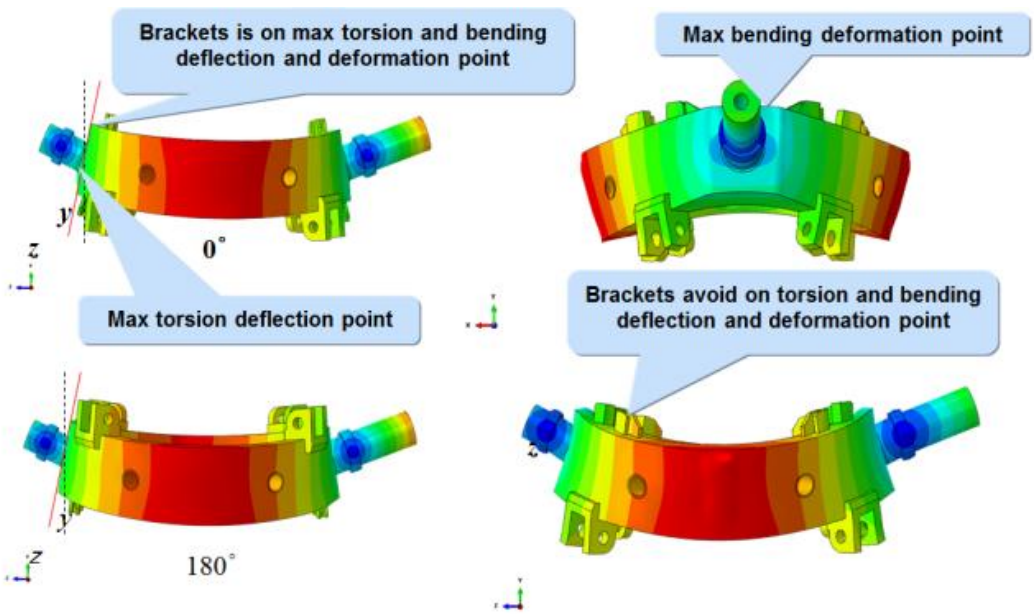

Figure 6 Finite Element Analysis: Different Layout (Location) of Block Seat has different AES and AMD [1, 3]

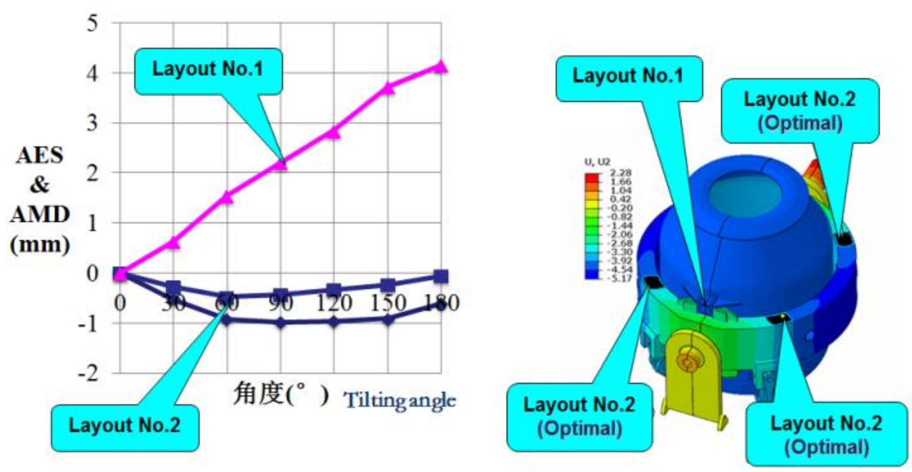

Figure 7 Finite Element Analysis: Optimizing the Position of the Horizontal Support Mechanism will Significantly Reduce AES and AMD

Through finite element analysis, dynamic simulation, and a lot of engineering practice verification: if the middle support points of the trunnion support block are dispersed to the place around the two trunnion support blocks, the mechanical system of the supporting and suspension system will be changed, and the supporting mechanism can avoid being located on the maximum torsion and bending deformation point of the trunnion support block of the trunnion ring [2]. When the horizontal support is set above the vertical connecting rod mechanism, the vertical connecting rod mechanism as well becomes the main mechanism restraining the "alternating displacement" AMD of the horizontal supporting mechanism on the supporting surface. Moreover, both the vertical connecting rod mechanism and the horizontal supporting mechanism are far away from the position with the maximum alternating displacement (~15mm) between the converter vessel and the trunnion ring, while the horizontal connecting rod mechanism is within the position with the minimum alternating displacement (1mm~2mm) between the converter vessel and the trunnion ring [1]; The position of the horizontal support mechanism is more reasonable, the installation "foundation surface" is more secure, the working condition is more ideal, the working life is longer, and the whole lower suspension adaptive suspension structure of the converter is optimized.

Based on the above analysis conclusion, CISDI changed the original horizontal block seat support position of the 250t converter of Baosteel Meigang to the position right above the vertical suspension mechanism of the converter vessel, immediately eliminating the vibration and abnormal sound of the converter, and the converter has been in good operation up to now. Given this, CISDI has successively shifted and reconstructed the block seats of the converter of Yangang, Hangang, Pangang, Xingang, Yinggang, and Chongqing Iron & Steel Co., Ltd. Which have similar block seats in the original design, and the running quality of the converter has been significantly improved. It can be seen that the functions and technical effects of the same block seat are different with different positions, which fully demonstrates the importance of setting the suspension positions of the converter.

Therefore, according to the finite element analysis in Figure 6 and Figure 7 above, dynamic simulation and a large number of engineering examples of CISDI, the ideal and optimal position for the layout of the suspension mechanism is that the horizontal support mechanism is located directly above the vertical suspension mechanism to ensure the running quality of the converter.

3 The Optimal Solution and Trend of the Converter Supporting Mechanism

Through the above analysis, finite element calculation, and a lot of engineering verification, the ideal and optimal technical scheme for the support structure of the 100t~500t converter is concluded as follows:

1) The optimal choice of suspension mechanism components is to use the connecting rod mechanism;
2) The optimal combination of the number of suspension mechanisms is to use 4 groups of vertical suspension mechanisms and 4 groups of horizontal supporting mechanisms;
3) The optimal position of the suspension mechanism is that the horizontal support mechanism is located right above the vertical suspension mechanism.

If the above three aspects are not reached or partially reached optionally, the converter running quality will be affected to a certain extent (which has been verified by a large number of actual projects at home and abroad); At the same time, meeting the above three items is the optimal combination of converter support technology. Its converter running quality must be excellent, which represents the world's leading converter support technology.

With the rapid development and progress of world science and technology, the research and development of various new mechanisms and the discovery and innovation of new materials in material science, the engineering and technical personnel constantly explore, research, improve and optimize the technology in these three aspects of suspension mechanism components, suspension mechanism quantity and suspension mechanism arrangement of the converter, which will improve the running quality of the converter, especially large converter, and the development trend and general direction of the converter support technology in the future.

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