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Analysis of Gas Duct Movement in Corex Process

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Abstract

This paper presents the analysis carried out for investigating the causes for Reduction Gas Duct (R.G.D.) movement in corex process. The predictive causes such as gas flow vibrations, wind baffling are not feasible because the duct is too huge to move by such reasons. So, the other causes for duct movement are investigated. The Finite Element Analysis (F.E.A.) of expansion joints in corex process has been carried out for analyzing such causes. The motion analysis of R.G.D. is also analyzed by considering expansion joint properties. The F.E.A. of expansion joints shows that the tie rods have stiffness greater than that of bellows. The stiffness of tie rods is considered for R.G.D. analysis. The results indicate that R.G.D. has displaced from its original position due to combined effect of pressure fluctuations and varying stiffness of expansion joints.

Keywords— *Bellows, Corex process, Ducts, Expansion joints, Tie rods*

1. Introduction

Corex process is one of the modern technologies used for iron making. This process utilizes the hot gases from the melter gasifier. The Reduction Gas Duct (RGD) used in this process has a slant duct below the reduction shaft as shown in Fig 1. The reasons for duct displacement could be due to gas flow vibrations, wind baffling and others. In this paper, the influence of back pressure and movement due to effect of expansion joint on RGD are analyzed.

The bustle is a part of duct which is used to distribute the gases inside the duct. It is placed annularly to the reduction shaft with gas ports leading into reduction shaft. The blockage of ports takes place due to dust particles. The accumulated dust particles are blown out by high pressure of the gas duct due to choking. Due to this blockage and subsequent blow-off, the pressure fluctuations takes place. The expansion joints are used at various locations of the ducts to carry gases at high pressure and temperature. These joints absorb vibrations due to flow of gases , variations in ducts due to the pressure and thermal expansion by the joints undergoing displacement. So, the effect of an expansion joint is to be considered while analyzing the RGD. This analysis is carried out by considering similar material for RGD and expansion joint.

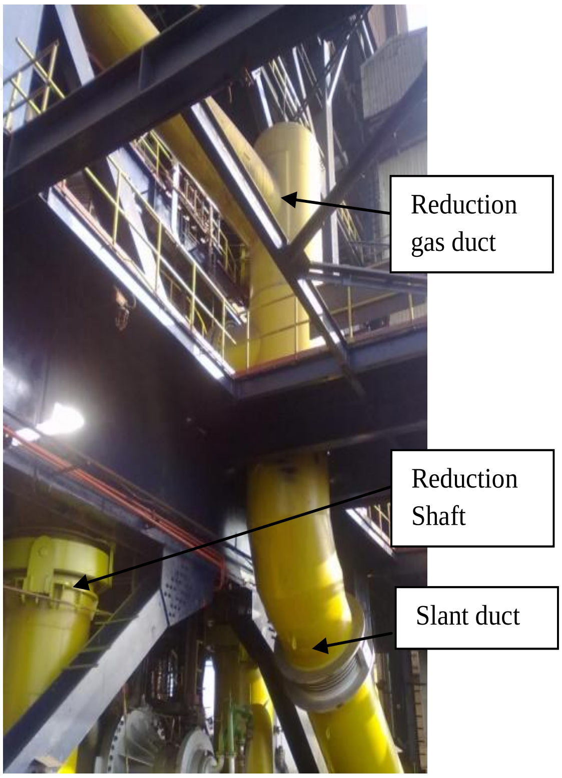


Fig 1 Reduction gas duct

The movement of duct is caused mainly due to back pressure generation with consideration of effect of expansion joint. These analyses are carried out by using finite element method by comparing it with analytical method.

2. Literature review

Several researchers have studied the corex process and expansion joints. Lampert K. and Ziebik A. [1] studied about CO_2 removal process from metallurgical fuel gases like blast furnace gas and Corex gas. They found out the solution for less use of coke in iron making processes. The physical absorption process was applied with the use of selexol solvent. The results indicate that physical absorption process may be useful method for CO_2 removal from blast furnace gas and Corex gas. Guo X.,Wu S., et al[2] optimized the reducing gas composition in Corex process. The reduction of carbon dioxide emission is required specially against global warming as there is a requirement of environmental protection. The researchers prepared a two dimensional mathematical model by considering mass, momentum, energy and chemical species. The best way to solve such problems is to increase the proportion of Hydrogen in the mixture of reducing gas. Li Q., Wei Y. et al [3] studied about unwanted deposition of particles on bend. Such particles decrease the efficiency of equipment. They used Laser Doppler Velocimetry (LDV) apparatus and experimental setup to study the velocity behavior of particles. Computational Fluid Dynamics (CFD) is also used to study the turbulent phenomena of dust particles. Researchers found out about particle concentration which influences degree of deposition of dust particles on the wall of duct. This factor should be taken into consideration while construction of duct.

Englund T., Wall J., et al [4] carried out theoretical modeling, simulations and experimental studies about flexible joints. A correlation between theoretical model and experimental results has been established. Design of such dynamic models were optimized by considering of physical and mechanical properties of flexible joints. Such simplified modeling is a valid approach to carry out non-linear analyses. Englund T., Wall J., et al [5] updated the procedure for simulation by using finite element software. The sum of differences between theoretically and experimentally obtained natural frequencies is chosen as an objective function to be minimized. The mode shapes obtained from simulation are correlated with theoretical values. It is found that the finite element model can be used in absence of actual prototype model. Englund T., Wall J., et al [6] modeled the bellows used in the expansion joint. The bellows are included in Corex process to allow movements and thermal expansion for reducing vibration transmission. The expansion Joint Manufacturing Association (EJMA) suggested the use of U-shaped bellows in expansion joints.

The aim of this paper is to investigate causes of longitudinal and lateral movements in the duct. The paper is organized as follows. The section 3 describes Corex process with the model of R.G.D. The section 4 gives explanation about expansion joints used in the corex process and application of expansion joint stiffness properties to part of RGD. Section 5 gives results and discussions related to Corex process. The conclusion of full paper is described in section 6.

3. Corex Process

The Corex process is considered as friendlier to environment than the blast-furnace process. This is because; non coking coal is used as a source of energy in Corex process. The Corex process consists of two separate reactors namely melter gasifier and reduction shaft.

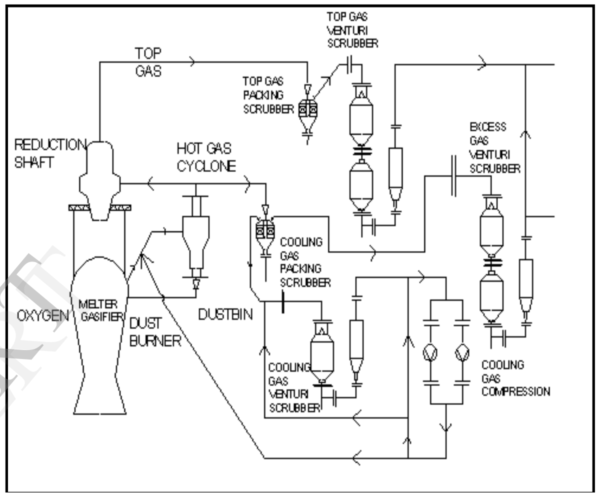


Fig 2 Process flow of Corex plant

The Fig 2 shows layout of process flow in Corex plant.The reduction of iron ore to sponge-iron takes place in reduction shaft and production of reducing gases and the melting of the sponge-iron are carried out in melter gasifier. The duct which connects outlet of hot gas cyclone and inlet of melter gasifier is called as reduction gas duct.

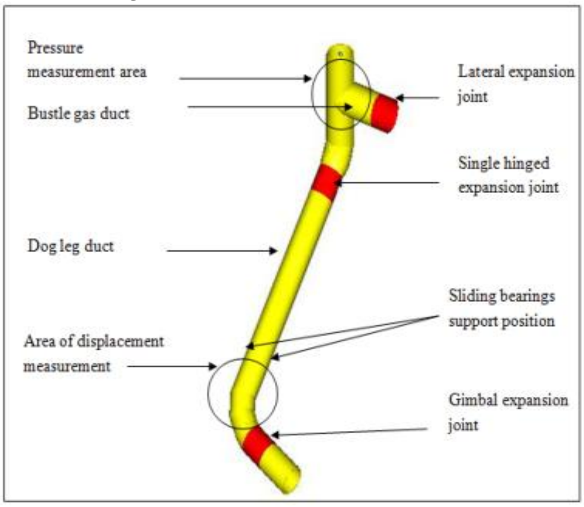


Fig 3 Structure of the R.G.D.

The Fig 3 shows structure of reduction gas duct with the expansion joints. It is modeled by using I-DEAS software for the analysis of movement. The circled area shown in Fig 3 shows the area of displacement. The displacement could be occurred due to pressure fluctuations of gases in the RGD. The pressure fluctuation data from Corex process is plotted with time for further simplifications in the readings. This simplification process is carried out to study the behavior of duct after pressure fluctuations.

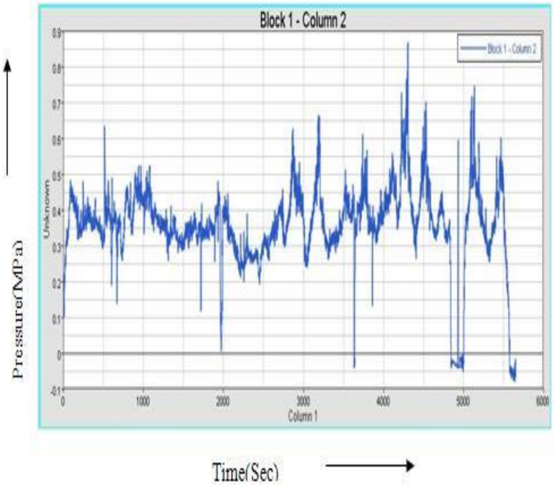


Fig 4 Pressure Vs Time graph

The Fig 4 shows Pressure Vs Time graph plotted in HyperGraph software. The readings plotted on graph is observed for 3 days. The FFT analysis is carried out to obtain the peak pressure value from these readings. For such complicated readings the graph is plotted for varying time of 300 sec.

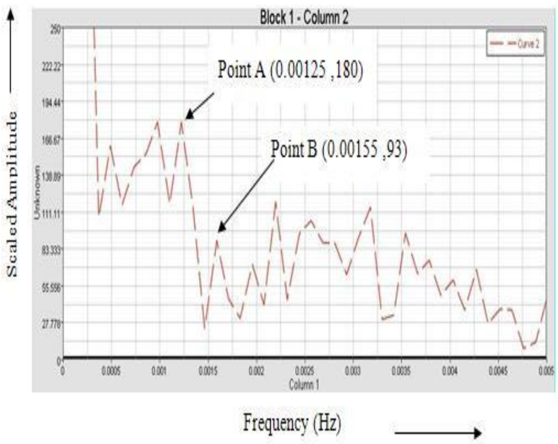


Fig 5 (Fast Fourier Transform) FFT analysis

The Fig 5 shows FFT analysis for pressure data shown in Fig 4. The frequency and scaled amplitude is plotted on x and y axes respectively. The two points A and B are shown in Fig 5. The point A indicates the frequency of 0.00125 Hz with the scaled amplitude of peak pressure is 180. Next peak pressure amplitude is 93. Maximum occurrences of pressure is 0.3 MPa.

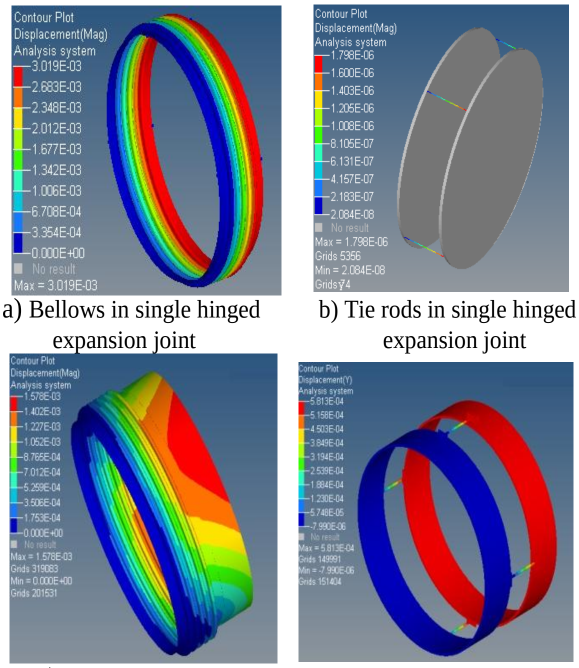
Table 1 Pressure calculations from FFT analysis

Sr.No.	Scaled amplitude	Pressure(MPa)
1.	180	0.3
2.	93	0.155

The table 1 shows calculations for pressure from FFT analysis. The pressure of 0.3 MPa is considered for 180 amplitude. So, relative pressure calculated for peak pressure amplitude of 93 is 0.155 MPa. The mean value of peak pressure is evaluated by considering half of the value coming from the next peak. The amplitude of pressure is considered as 0.0775 MPa. The frequency 0.00125 Hz has peak value of (180). So, period of $\frac{1}{frequency}$ seconds has to be taken for completion of one cycle. It means that for completion of one cycle of pressure fluctuations, 800 seconds are required. The pressure fluctuation of gases in the duct is the main cause for movement. The movement could be occurred due to expansion joint effect. So, the expansion joints are studied in the next section of the paper.

4. Expansion Joints

The expansion joints are used to compensate the movement of ducts and to absorb the vibrations due to gas pressure in ducts. Various types of expansion joints have been studied for analysis because all of them are having different behavior. One of them is lateral expansion joint. A lateral expansion joint is designed to carry out lateral movement to compensate the pressure variation and displacement in the ducts. The lateral expansion joint is located at the joint of RGD and reduction shaft. The second type of expansion join joint used in RGD is single hinged expansion joint. The single hinged expansion joint allows the angular rotation in only one plane. It is located at the joint of RGD and dog leg duct. Third type of expansion joint used in RGD is gimbal expansion joint. The gimbal expansion joint allows rotational and angular movement. It is located below single hinged expansion joint. The location of Lateral expansion joint, single hinged expansion joint and gimbal expansion joint are shown in Fig 3. The expansion joints used in corex process have two components to absorb the pressure thrust viz. bellows and tie rods. The finite element analysis is carried out for obtaining the displacement of bellows and tie rods.



a) Bellows in single hinged expansion joint

b) Tie rods in single hinged expansion joint

c) Bellows in lateral expansion joint

d) Tie rods in lateral expansion joint

Fig 6 Displacement contours for various components of expansion joints

The Fig 6 shows displacement contours for bellows and tie rods in single hinged expansion joint and lateral expansion joint. The bellow and tie rod used in expansion joint are applied with a force of 1N from one side keeping the other side fixed. It is observed from the analysis that the displacement of the tie rod is lower than the displacement of bellows. This displacement is obtained for calculating stiffness of bellows and tie rods. The stiffness of the bellows and tie rods can be obtained by the formula:

$$K = \frac{F}{x} \tag{1}$$

Where, K = stiffness in N/mm

F = force applied in N

x = displacement in mm

The stiffness is obtained by substituting displacement values from Fig 6 in equation (1). The tie rods are having higher stiffness than stiffness of bellows. It is proved with the finite element analysis that the tie rods absorb all the pressure thrust by gases. Hence the stiffness of tie rods has been considered while analyzing reduction gas duct.

5. Results and Discussions

The analysis of RGD movement has been carried out in MSC- ADAMS software. The stiffness is classified into two parts as per the construction of various expansion joints viz. Translational stiffness and Rotational Stiffness. They are given in Table 2 and Table 3.

Table 2 Translational Stiffness of expansion joints

Sr. No.	Direction of translational stiffness	Stiffness of lateral expansion joint (N/mm)	Stiffness of gimbal expansion joint (N/mm)
1.	X	5.58×10^5	8×10^7
2.	Y	1720	8×10^7
3.	Z	1720	8×10^7

Table 3 Rotational Stiffness of expansion joints

Sr. No.	Direction of rotational stiffness	Stiffness of lateral expansion joint(Nmm/deg)	Stiffness of gimbal expansion joint(Nmm/deg)
1.	X	8×10^{17}	8×10^{12}
2.	Y	8×10^{17}	85.5
3.	Z	8×10^{17}	85.5

The Table 2 and Table 3 gives translational and rotational stiffness of tie rods. The lateral expansion joint is having very high rotational stiffness because it gives very small angular displacement in rotational degrees of freedom.

The stiffness of gimbal expansion joint in translational directions is considered as very large because it gives very less displacement in translational directions. The stiffness of gimbal expansion joint are assumed with the help of EJMA standard. The observations in Table 4 are obtained after analysis of duct by substituting the values of stiffness and forces. A force of 3.68×10^5 N has been applied on the RGD by considering inside pressure of gases and cross sectional area of the duct.

Table 4 Displacement of duct in X, Y and Z direction

Sr No	Time for duct to move (in sec)	Displace-ment of duct in X-direction (mm)	Displace-ment of duct in Y-Direction (mm)	Displace-ment of duct in Z-Direction(mm)
1	0	0.9164	0.3772	0.4013
2	800	0.9122	0.3446	0.4013

The Table 4 shows displacements of ducts in X, Y and Z direction. There is very slight difference in the displacements as these displacements are observed for 800 seconds.

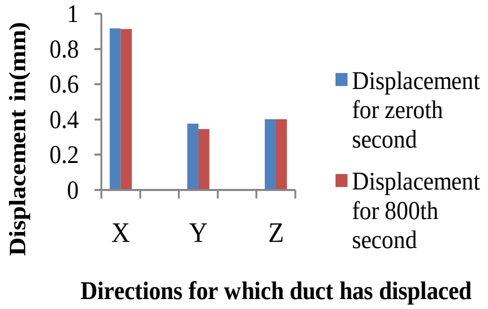


Fig 7 Comparison of displacements

The Fig 7 shows a graph of comparison between obtained displacement and actual displacement in RGD. This graph has been plotted as per the readings shown in Table 4. The graph indicates that the duct has displaced from its original position in X and Y directions only. The readings required for this graph are obtained after motion analysis of RGD in MSC-ADAMS software. The motion analysis is carried out for 800 seconds because one cycle of the pressure is completed in 800 seconds with reference to Fig 5. The total displacement of the duct is extrapolated by using the formula from equation (2).

$$D_T = D \times N_H \times N_Y \times N_{SD} \times M \qquad (2)$$

Where, D_T = Total displacement,
D = Displacement obtained from motion analysis,
N_H = No. of hours in a day = 24 Hrs,
N_Y = No. of years for observation of pressure fluctuations = 7 years,
N_{SD}= No. of days for shutting down the plant within year = 6 days,
M = Multiplying factor to calculate the displacement for 1 hour (3600seconds) = 4.5
By substituting these respective values from the analysis following results are obtained.

Table 5 Comparison of displacements

Sr No	Direction of displace-ment	Actual displacement (mm)	Simulated displacement (mm)
1	X	15	19.0512
2	Y	55	32.6592
3	Z	0	0
Resultant Displacement		57	**38.596**

The Table 5 shows comparison of displacements between actual displacement and simulated displacement. The difference in displacement is mainly due to approximate method of simulation.

6. Conclusion

The finite element analysis shows that the stiffness of tie rod is more than stiffness of bellows. The motion analysis of RGD gives the displacement value after substituting the stiffness of tie rods. It can be compared with the actual movement. The difference in the displacement is due to approximation in the method of analysis. The result indicates that the reduction gas duct movement is mainly due to pressure fluctuations. The expansion joints also affect the duct movement because all types of expansion joints used in corex plant have various stiffness. The effect of back pressure can be controlled by cleaning of bustle ports when high pressure fluctuations are observed. It is necessary to study and re-design the expansion joints located in the corex plant.

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