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ON THE CONTROLLED CHARGING OF BLAST FURNACES[1]

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Abstract
The demands technology of charging blast furnace can be met while fulfilling three prerequisites. Number one, the charging device must be capable of achieving a high degree of circular uniformity in distributing burden material and a flexible control of ore/coke rations along the furnace top radius. Number two: the charging device must be equipped with means to monitor the charging technology on-line. And number three - ACS must support the optimum distribution of ore/coke rations along the furnace radius, using feedback of furnace performance data. The above-said prerequisites have been partially put into effect and are still under development on blast furnace № 2 at JSPL Steel plant of Jindal Corporation in India. This furnace is Equipped with the bell-less rotary charging unit (BRCU). Nowadays the installation of automatic system called "TOTEM Top Scan" for monitoring the charging process is under implementation.
Key words: Blast furnace; Distributing burden; Bell-less top rotary device; Charging.

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1 INTRODUCTION

The production of hot metal to-day demands much for the technology of charging blast furnaces. These demands can be met while fulfilling three prerequisites. Number one, The charging device must be capable of achieving a high degree of circular uniformity in distributing burden material and a flexible control of ore/coke ratios along the furnace top radius. Number two: the charging device must be equipped with means to monitor the charging technology on-line. And last but not least, number three – ACS must support the optimum distribution of ore/coke ratios along the furnace radius, using feedback of furnace performance data. The above-said prerequisites have been partially put into effect and are still under development on blast furnace No. 2 at JSPL steel plant of Jindal Corporation in India. This furnace is equipped with the bell-less rotary charging unit (BRCU). Nowadays the installation of automatic system called "TOTEM Top Scan" for monitoring the charging process is drawing to a close.

2 DISCUSSION

At present one can sum up a six year experience of operating a bell-less rotary charging unit (BRCU) in India on BF-2 at JSPL steel plant (Jindal Group).Table 1 shows alterations that occurred in the yearly mean performance indices of this furnace over financial years 2007 – 08; 2008 – 09 and farther. The data in Table 1 testify to the fact that the performance indices of BF-2 were gradually improving both in terms of fuel rate and productivity. This continuous growth was mainly caused thanks to the adaptation and optimization of innovative technology, named the rotary charging of burden.
It should be noted that the raw material supply was practically steady all that time.

Table 1. Alterations in BF-2 performance indices, by years

Indices	2008	2009	2010	2011
Coke rate, kg/t	465.5	399.35	385.36	346.66
CDI rate, kg/t	87.51	131.53	142.77	156.98
Summary fuel rate, kg/t	553	530.87	528.14	503.64
Carbon rate, kg/t	463.6	439.57	433.69	416.41
CO utilization rate, %	44.55	45.32	46.5	47.24
Si in hot metal, %	0.746	0.55	0.5	0.47
Slag yield, kg/t	320.68	295.06	287.84	293.68
Daily productivity, t/day	3206.6	3474.9	3596.4	3765.4
Specific productivity $t/m^3 \cdot d$	2.26	2.47	2.52	2.62

To-day the rated performance indices of the blast furnace have been substantially exceeded. Figure 1 shows a diagram to illustrate how the CO utilization rate has been growing in time and Si in hot metal falling down. The growth of the CO utilization rate year in year out testifies to the fact that the distribution of burden was improving in step with the adaptation of the innovative rotary charging technology. Improvements in the burden charging practice resulted in making the furnace performance stable, which is turn made it possible to decrease Si content in hot metal and reduce the coke rate. Thus, the experimental data generated earlier had been corroborated to the effect that the circular and radial distribution had improved thanks to the rotary apparatus [1]. According to the experimental data, the circular non-uniformity in terms of material weight at the distribution of burden by rotor, in standard deviation came to 1.88%, and non-uniformity of fines distribution - 2.8%. These indices are lower then those demonstrated by the chute-type apparatus 2.6 and 4.6 times.

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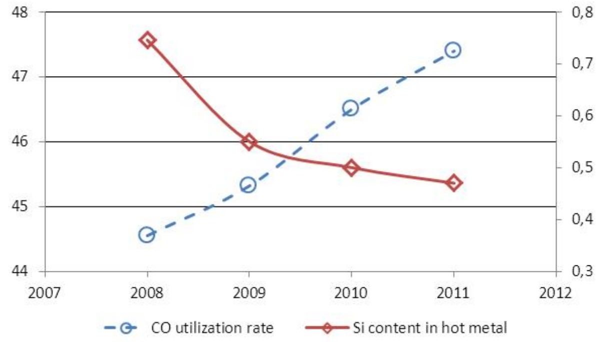

Figure 1. Alterations in CO utilization rate& Si content in hot metal.

However, the evidence of BRCU advantage would have been incomplete without comparing BF-2 performance with a sound performance of a blast furnace with a chute-type apparatus. For this purpose blast furnace "G" was chosen at Tata Steel. Table 2 contains comparative analysis data obtain from both these furnaces. All the presented data are monthly mean values and obtained from the reports of the plants concerned. The reason why furnace "G" was chosen is that both the compared furnaces had been operated under similar conditions in terms of raw material supply and slag like content, the latter being quite specific in India. Of no small importance was the fact that furnace "G" would feature the best performance indices in India, which made the comparative analysis more unbiased and impartial.

Table 2. Comparative Analysis of Performance Parameters of BF-2 of JSPL and BF-"G" of TATA STEEL

Performance Parameters	Tata Steel May07	JSPL Mar.09	JSPL Apr.09	JSPL Dec.10	JSPL Nov.11
1. Productivity, t/day	5476	3667	3617	3956	3978
2. Down time, %	0	3.26	2.94	n.a.	2.36
3. Specific prod-ty , $t/m^3\cdot day$	2.37	2.51	2.47	2.73	2.72
4. Coke rate (incl. coke nut), kg/t	419	399.8	382.2	342.11	333.73
5. PCI rate, kg/t	141	131.8	142.6	168.09	164.5
6. Total fuel rate, kg/t	560	531.6	524.8	510.2	498.23
7. Carbon rate, kg/t	477	439.4	433.5	413.56	405.54
8. Ore rate (dry), kg/t	502	590	520	531	372,0
9. Sinter rate kg/t,	1042	1060	1130	1105	1200
10. Quartzite rate, kg/t	13	5.2	16.76	1.92	2.43
11. Fe in ore part of burden, %	58.97	58.46	57.47	58.68	58.31
12. Blast temperature, ºC	1136	1195	1187	1194	1179
13. Top pressure, bar	1.54	0.89	0.87	1.06	1.08
14. Pressure differential, bar	1.63	1.75	1.76	1.65	1.65
15. O_2 in blast, %	25.35	24.63	24.71	25.8	25.26
16. Blast moisture, g/m^3	31	34.8	41.3	9.66	9.17
17. Slag yield, kg/t	263	289.5	311	298.4	295.04
18. Top temperature, ºC	No data	104	110	111.1	91.23
19. CO utilization rate, %	44.36	46.08	45.97	46.01	47.29
20. Si in hot metal, %	0.8	0.53	0.52	0.48	0.43
21. Slag chemistry, % Al_2O_3	18.75	20.48	20	20.08	25.26
MgO	6.62	9.12	9	9.64	8.4
CaO/SiO_2	0.99	1.02	0.99	1.0	1.05
22 Coke quality, %, CSR	65.01	64.57	64.6	68.94	66.0
M10	5.2	5.52	5.43	5.66	5.24
Ash	13.72	12.45	12.38	12.53	12.34
23. PCI quality, % Ash	10.41	9.83	9.73	11.12	11.87

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The cumulative part of Table 3 shows respective improvements in BF-2 performance indices as compared with furnace “G”. These data are of sufficient evidence that the rotary method of burden distribution has a pronounced and substantial edge over the chute-based methods.

It should be also noted that the BF-2 personnel was a success in working out and optimizing the charging patterns. A two-batch mode of charging was worked out. In this mode corrections in the radial distribution of material have to be made for one component only. Such a system makes it possible to execute a flexible control of ore/coke ratios along the radius and make corrections on-line in step with the alterations in the furnace performance. A detailed description of the burden charging system is expounded in work [2].

On the whole, the analysis of BF-2 performance shows that BRCU as a tool of control of the furnace has proved its high efficiency, as it would substantially improve the circular uniformity of burden distribution and could be used in a flexible manner to adjust the radial distribution of ore/coke ratios.

So, the prerequisites have been created to upgrade the heats technology on the basis of BRCU utilization. These prerequisites are rooted in the visualization of the charging process.

Table 3. Improvements in Basic Operating Parameters of BF-2, JSPL in Comparison with BF “G”, TATA STEEL, (%)

Month	Mar.09	Apr.09	Dec. 10	Nov. 11
1. Specific productivity	+5,91	+4,22	+15,19	+14,77
2. Coke rate	-4,58	-8,78	-18,35	-20,35
3.Total fuel rate	-5,07	-6,29	-8,89	-11,03
4. Carbon rate	-7,88	-9,12	-13,30	-14,98

3 TTS OPERATING PRINCIPLES

TTS shows the schematic diagram of TTS. The key members of Totem Top Scan (Fig.2) are as follows:

- Measuring units, based on radars that would emit high frequency electromagnetic directed radiation.
- Banks of electromagnetic radiation reflectors. On each rotor vane there two reflectors will be installed to measure the distance to two points on the burden surface.

The measurements are taken in the intervals between the charges of material, at the moment when a reflector would appear in front of the measuring unit (radar) of the reflector. A signal from the radar is directed by the reflectors to the burden surface, wherefrom it will be reflected again and a part of the radiation from the burden surface would come back to the reflectors, that in turn redirect a part of the reflect signal to the measuring units receivers (Figure 2).

The signal thus received is processed in the measuring unit and then re-calculated into the distance from the level “0” to the burden surface. All measurements are taken on-line. The total number of measurements taken by 6 radars that are installed in the furnace circumference and by 10 reflectors (two on each vane) is 60. The interval between the charging of batches is 1.5 – 2.0 minutes, which is enough for

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taking two measurements of burden profiles just before such charging and immediately after it. These measurements make it possible not only to plot the burden profile, but to depict graphically the cross sections of each batch of burden material. After that the processed initial data are sent to the measuring signals processing unit, which is industrial PC with required software. The initial data are processed in this unit, the above-said burden profiles are plotted as well as radial ore/coke ratios, burden descending rate epures and other charging parameters.

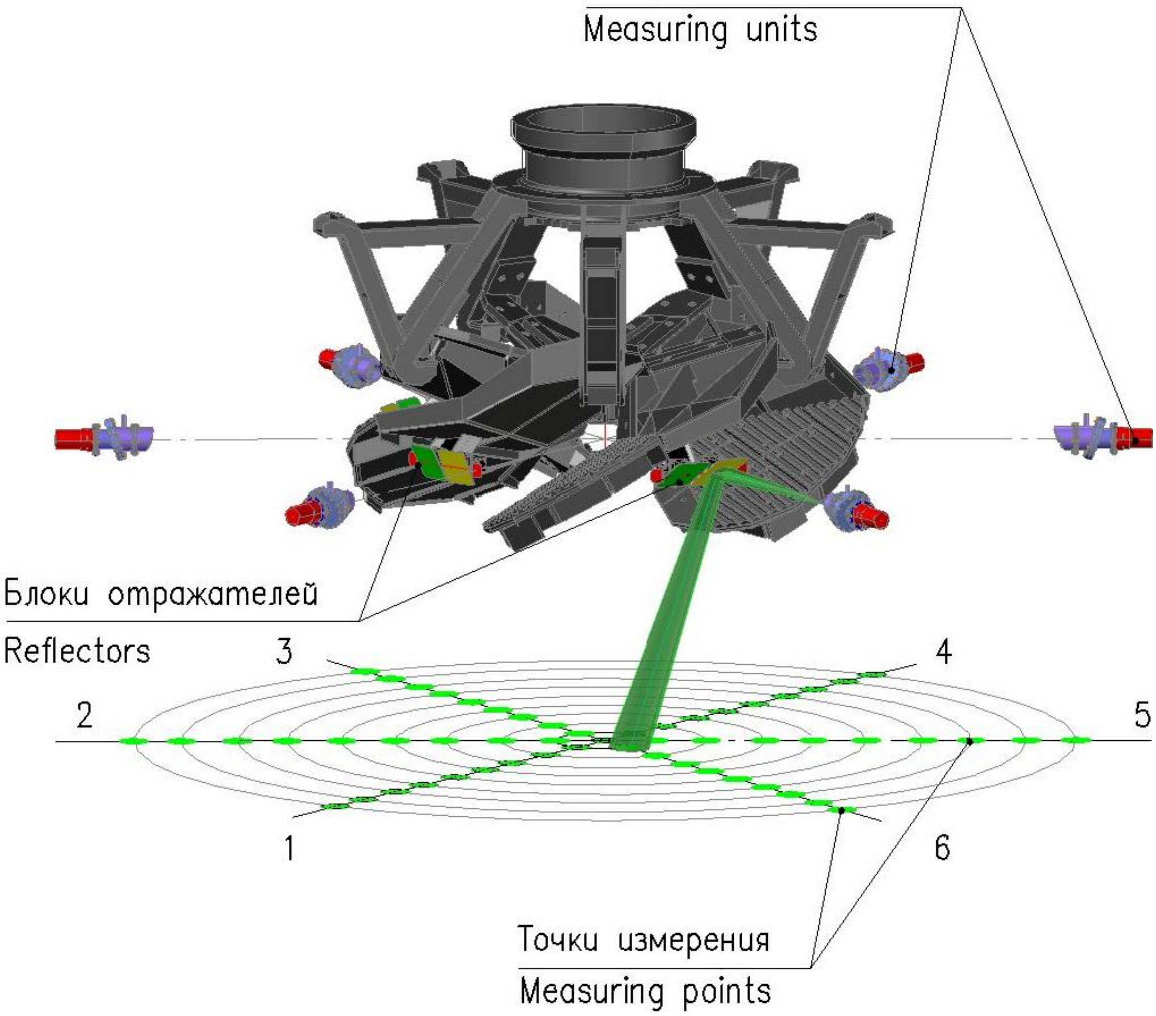

Figure 2. TTS components .

4 FUNCTIONAL DESIGNATION OF TTS

The main functions of TTS are as follows:

- Construction of topography of layer-wise stacking of burden at the blast furnace top.
- Determination of criteria for the radial distribution of material on the basis of the topography generated and with due account of burden descending rate.
- Provision of feedback on the basis of determined dependences of the iron making process on the burden charging criteria.
- Development of recommendations to correct the radial distribution of material on the basis of feedback received.

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5 MEASURED AND COMPUTED PARAMETERS

The main measuring parameter of TTS is the distance between the burden surface and notch "Zero", from which the stock line level is calculated. Measurements are taken at 60 points on the burden surface and executed on-line. The other parameters that are determined by TTS, are derivatives from the measured distance. All the measurements have to be synchronized in time. In Table 4 there is a list of parameters that are determined by TTS. Those are needed to work out recommendations to optimize the charging of the blast furnace.

Table 4. List of parameters determined by TTS

1.	**Measured parameters**
1.1.	Distance between the burden surface and notch "zero" (60 points)
2.	**Derivative parameters**
2.1.	Profiles of the burden surface after each charged batch
2.2.	Profiles of layers in each batch of burden within one cycle
2.3.	Epures of burden descending rate by radial sections of the top
3.	**Computed parameters**
3.1.	Radial ore/coke ratios
3.2.	Radial ore/coke ratios as averaged by several sections
3.3.	Criteria of the stock radial distribution *)
3.4.	Epure of the burden descending rate as averaged by the burden sections
4.	**Statistical parameters***
4.1.	Statistical parameters on the circular distribution of burden
4.2.	Statistical parameters on the circular burden descending rate
4.3.	Search for the statistical linkage between the charging parameters and blast furnace performance indices.

Notes: * List of computed and statistical parameters of ACS amay be broadened after the implementation of TTS.

The recommendations based on the monitoring of the charging process will be issued mainly with reference to the criteria for radial distribution of stock. Below there are these criteria, that have been formulated by us in work [3].
To compute the criteria, the top span had been conditionally split into 6 equal-in-area annular zones. It was suggested to use three dimensionless criteria for the radial distribution of burden in the given cycle of batches.

$$\mathbf{CD1} = \frac{\text{mean ore/coke ratio in annular zones } 4 \div 6}{\text{mean ore/coke ratio in annular zones } 1 \div 3}$$

$$\mathbf{CD2} = \frac{\text{mean ore/coke ratio in annular zones 5 and 6}}{\text{mean ore/coke ratio in annular zone 1 (center)}}$$

$$\mathbf{CD3} = \frac{\text{mean ore/coke ratio in annular zones } 2 \div 4}{\text{mean ore/coke ratio in annular zone 1 (center)}}$$

Here CD1 is the relationship of ore/coke ratios in 3 peripheral zones of the furnace with the ore/coke ratios in the central annular zones of the furnace.
CD2 and CD3 these are the relationships of ore/coke ratios in 2 peripheral zones with the ore/coke ratio in the central ring and in three intermediate zones with ore/coke ratio in the furnace central zone.
On the whole, all these three criteria reflect quantitatively the asymmetry of in the distribution of ore/coke ratios along the furnace radius, which makes it possible to understand their interrelation with the furnace performance indices.

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To assess the significance of effects of the charging patterns which would be characterized by the radial distribution criterion CD1, upon the furnace performance indices, it was decided to assume as such indices the CO utilization rate and specific fuel rate. A mathematical model was used to visualize the charging process and determine CD1. Calculations were made on the basis of daily data and the most typical patterns of charging. Estimated values of CD1, actual values of CO utilization rate and specific fuel rate in the given 24 hours are shown in Table 4.

It is obvious, that there should be a close correlation between the specific fuel rate and CO utilization rate. Quantitatively, for the operating conditions of BF-2 this correlation is shown in Figure 3. The growth of CO utilization rate by 1% resulted in reducing the summary fuel rate by 20 kg.

Table 5. Effect of CRD1 upon the blast furnace performance indices

Date	08.06.2007	26.09.2007	12.10.2007	28.10.2007	28.11.2007	11.12.2007
CD1	0.972	0.797	1.116	1.124	1.609	n/a
CO utilizat. rate. %	45.01	43.91	44.74	44.66	45.48	45.93
Fuel rate kg/t	545.1	558.8	546.2	544.1	526.7	513

It should be taken into account that to plot this dependence we selected daily mean data without putting them to preliminary filtration and synchronizing them in time, and the criterion proper was determined with the help of a mathematical model, but not through direct measurements by TTS.

In the discussed analysis we have not been able so far to assess the efficiency and promising value of the criteria of radial distribution of burden – CD2 and CD3. But there is a strong belief that in future, when a more thorough research would be carried out after the complete implementation of TTS, their efficiency will be proved.

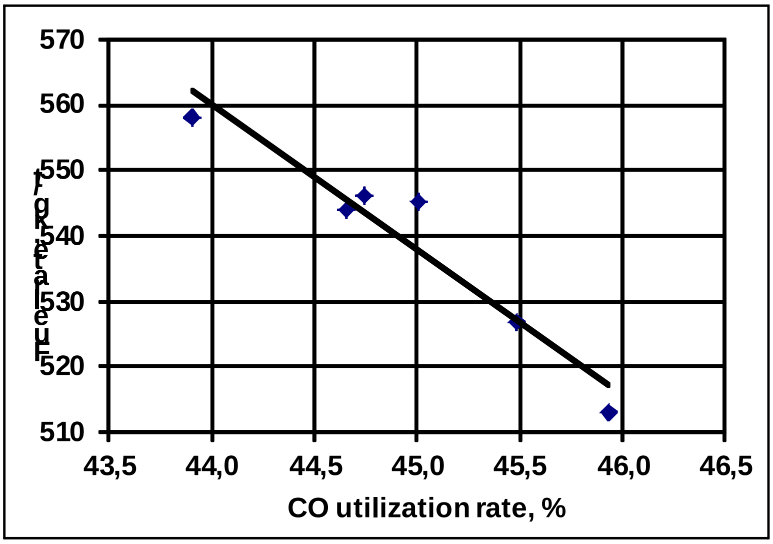

Figure 3. Correlation between the specific fuel rate and CO utilization rate.

Figure 4 shows a graph of dependency of the CO utilization rate on the value of CD1, plotted on the basis of data from Table 2. As one can see, there is a legible trend between the discussed parameters, which can be expressed as a polynomial to the 2nd power.

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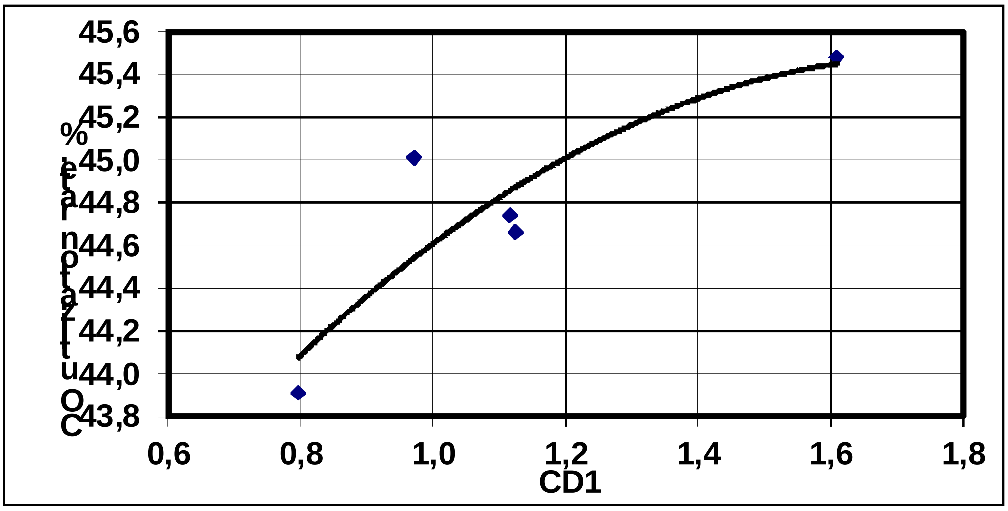

Figure 4. Dependence between CD1 and CO utilization rate.

In our opinion, after having the monitoring procedures streamlined and rectified and data synchronized with the help of TTS, interrelation with a higher degree of variables correlation will be obtained. They will be suitable for the development and implementation of an automatic system to control the blast furnace charging process. To design such a system in future is a paramount task of our research and development work.

6 CONCLUSIONS

A six year experience of using the rotary charging technology in BF-2 at JSPL (Jindal Group) has proved that BRCU is a flexible and efficient tool for controlling the distribution of stock at the blast furnace top, which has made it possible to upgrade significantly the blast furnace performance indices.
To improve the blast furnace performance indices further endeavors have been started to implement a system for monitoring the burden charging process with the help of a radar-based scanning of burden surface (Top Scan System – TTS) along 6 radii simultaneously, in an on-line mode.
The criteria for the optimization of radial distribution of ore/coke ratios have been worked out.
The finite aim of the TTS implementation project is to engineer an automatic control system for charging burden into a blast furnace.

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