THE SIMETAL^{CIS} GIMBAL TOP® "GOES LIVE"[1]

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Abstract
The world's first Gimbal charging system has now undergone extensive field trials in preparation for going operational on 'C' Blast Furnace at Tata Steel. This paper will describe the rational behind the trials, the results obtained from the test program of this SGT3000™ model. The SGT3000™ unit is now installed and when operational will become the world's first Blast Furnace charging system to give infinite charging pattern flexibility.
Key words: Operational tests; Burden distribution; Blast furnace charging.

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Resumo
O primeiro sistema de carregamento Gimbal está sendo agora submetido a uma série de testes de campo em preparação para entrar em operação no Alto Forno "C" da Usina Tata. Este trabalho descreve a lógica por trás das experiências, os resultados obtidos do programa de teste deste modelo SGT3000™. A unidade SGT3000™ agora está instalada e quando entrar em operação será o primeiro sistema de carregamento de Altos Fornos do mundo a dar flexibilidade infinita aos padrões de carregamento.
Palavras-chave: Testes operacionais; Distribuição de carga; Carregamento de alto forno

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INTRODUCTION

An order for the world's first blast furnace charging system incorporating the Gimbal Top® was placed with Siemens Metals Technologies (MT), by the Indian steel producer Tata Steel Ltd in April 2007 as part of the scheduled re-build of 'C' Blast Furnace at Jamshedpur in Jharkhand province, India. During the execution of this project, the charging system has undergone rigorous operational tests at the customers Jamshedpur works, India, marking another major milestone in the product development.

The aims of the tests were to validate all aspects of performance for the top charging system against the required parameters for the new 'C' blast furnace operation. In addition, Tata Steel Ltd operating and maintenance personnel would be afforded the unique opportunity to become familiar with all aspects of the equipment performance and maintenance prior to its installation on the new furnace.

Figure 1: Gimbal Test Facility at Tata Steel Ltd.

During the three month test programme in excess of three hundred individual material tests were completed with Iron Ore, Coke and Sinter, during which time the following operating discharge cycles were completed.

- Iron Ore - 95 discharge cycles
- Coke - 130 discharge cycles
- Sinter - 87 discharge cycles

OPERATIONAL TEST FACILITY

The operational test facility utilised incorporated all critical elements of the 'C' furnace top charging system, including receiving chutes, upper lock valves, material receiving hopper 9m^3 capacity, material flow gate, lower lock valve, expansion bellows and SGT3000^{Tm} gimbal distributor. The system tested and ultimately destined for the furnace installed was a single hopper, central feed, pressurised charging system designed for a single skip charge of 6.85m^3 capacity.

Figure 2: The SIMETAL^{CIS} Gimbal Top® Charging System.

The test facility infrastructure provided in conjunction with Tata Steel Ltd was designed to incorporate the following aspects designed to allow the tests to simulate actual furnace operation:

- Concrete retaining wall providing a simulated throat diameter of 5.9m
- Material collection boxes positioned at the Upper and Lower Stock line levels
- Local control of the Hydraulic Upper and Lower Lock valves by manual push button
- Manual control of the Hydraulic Material Flow Gate via a PLC
- Auto control of the Distribution Chute via a PLC
- Monitoring of Hopper weight by load cell.

As with the ultimate blast furnace implementation, control of the gimbal distribution chute was by means of a proprietary control and feedback system, supplied by Siemens MT, which is fully integrated into the overall furnace charging software. For the purposes of operational testing, control of the Gimbal Top® distributor was achieved utilising a standalone PLC connected to a high speed multi-axis hydraulic controller via a net work cable with a lap top simulating the main HM interface.

Material for testing was charged to the receiving hopper of the charging system by crane with feed to the distributor via the hopper and valves achieved by manual sequencing the charging system with the following charging patterns available for testing.

- Spot – any static position within the furnace throat.
- Ring – rotations at 0-8rpm and tilt angles from 0-38^{o} tilt.
- Spiral – spiral charging sequences with up to 11 rings selected.
- Sector – any portion or sector of a chosen ring at rotations from 0-8RPM. (increments of 1^{o} from 0-360^{o})
- Wave – a pre-described sinusoidal wave charging sequence for demonstration of non-ring based distribution.

During the trajectory and distribution trials a series of material collection trays were positioned at the higher and lower stock line levels around the furnace throat to

collect discharged materials as a means of identifying and analysing impact and distribution. During individual tests a photographic and video record was also taken of material discharge from the tilting chute to allow the study of discharge characteristics when compared to the distribution data.
The size distribution, by percentage weight, and bulk density of burden materials utilised during tests is shown below:

Material	Size Distribution (% Wt)							Bulk Density
	+50	+40	+30	+25	+10	+8	-8	Te/m^3(lbs/cu.ft)
Iron Ore	0	0.7	11.5	14.1	42.2	18.8	9.8	2.56 (159.6)

Material	Size Distribution (% Wt)							Bulk Density
	+50	+40	+25	+15	+10	+5	-5	Te/m^3(lbs/cu.ft)
Sinter	13.4	6.9	17.2	19.2	14.4	20.3	8.6	1.92 (120)

Material	Size Distribution (% Wt)						Bulk Density
	+100	+80	+50	+40	+30	-30	Te/m^3(lbs/cu.ft)
Coke	35.1	28.4	32.4	1.0	1.7	1.4	0.62 (38.7)

MATERIAL FLOW GATE TESTING

The purpose of material flow gate testing was to validate the operating range of material flow for Iron Ore, Sinter and, Coke that could be achieved with the furnace top charging system and therefore determine the optimum settings for furnace operation. The rate of material flow was determined via the recorded output from the load cells monitoring the material stored in the receiving hopper. The optimum operational flow rate of 0.42m^3/s required for the charging system was determined from the production data shown below whilst producing an overcharge capacity of 22% and satisfying the customers preference to discharge burden material with each individual skip discharging in two (2) concentric rings.

- Iron Production 2100 Tonnes per day
- Coke Rate 500 kg/ Thm
- Coke Batch Volume 13.7m^3
- Skip Cycle 73 seconds

As can be seen in figure 3 below the material flow gate utilised in this furnace charging system was a “clam shell” type gate of 650mm (2ft 2ins) diameter. The gate was a hydraulically operated, modulating valve with its position monitored by an encoder mounted directly to the actuating shaft. The figure shows a graphical representation of the discharge area presented versus the percentage of material flow gate opening.

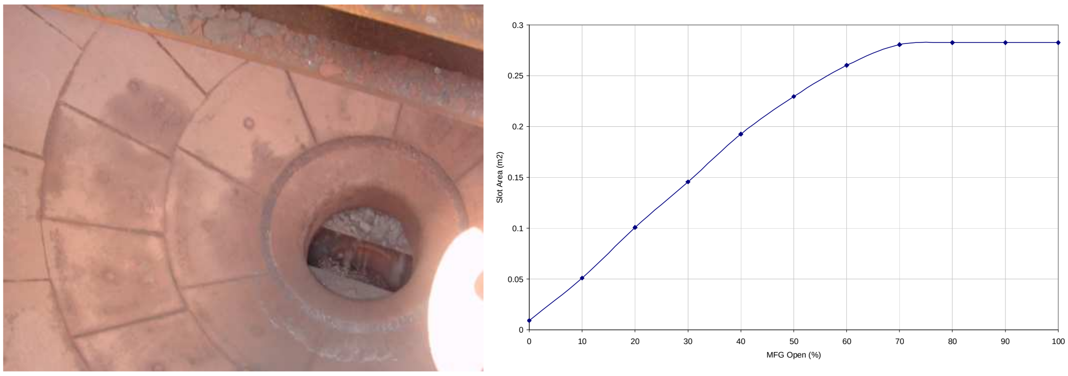


Figure 3: Material Flow Gate – Gate Area vs. Opening.

It was noted that although the material flow gate presented a maximum discharge area when 70% open, whilst it can be seen from the below graph that peak material flow was actually achieved at 60% open. This peak flow condition was achieved when the discharge area presented by the material flow gate was equivalent to that of the 600 mm (1ft 11ins) opening of the distributor's fixed inlet chute.

A series of tests were completed to validate the operating range of the material flow gate and to determine the required operational settings for the gate in-order to achieve the required flow rate of $0.42m^3/s$ (14.84cu.ft/s). Results obtained for gate openings between 10% and 100% were recorded to provide a comparison of material flow versus percentage gate opening for all four burden materials tested, the results are shown in Figure 4 below.

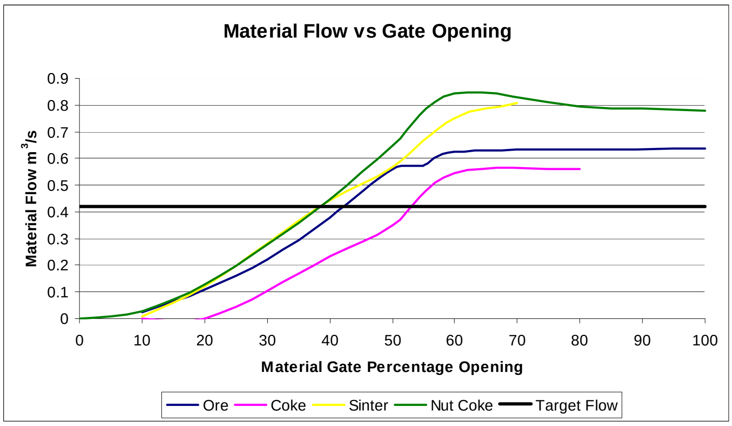


Figure 4: Material Gate – Flow vs. Percentage Opening.

From the test data recorded the following conclusions were drawn with respect to material flow. Firstly, that for the known burden materials to be utilised in the future operation of 'C' blast furnace, the optimum operational flow rate could be achieved and in all cases exceeded. Secondly, that the following material flow gate openings required for the optimum operational furnace charging rates were verified as follows:

- Coke – 53%
- Iron Ore – 42%
- Sinter and Nut Coke – 38%

Finally, as previously determined by calculation, for all burden materials, maximum flow was achieved at approximately 60% opening of the material flow gate at which point the flow will be dictated by the discharge area presented by the distributor's fixed inlet chute.

MATERIAL TRAJECTORY TESTING

The purpose of material trajectory testing was to validate the operating falling curves for Iron Ore, Sinter and Coke with the furnace top charging system utilising the unique conical distribution chute and thereby determine the optimum settings for furnace operation. In addition, as an integral part of trajectory testing it would be necessary to confirm that all burden materials were capable of reaching the furnace throat at the upper and lower stock line levels specified for ‘C’ blast furnace.

When considering the necessary charging performance for the throat and high stock line required for the ‘C’ furnace project, based upon development test results, a triple cone profile was adopted for the 2.19m long conical tilting chute. Siemens MT believe that this unique multi-cone feature can be exploited to allow a range of charging solutions to be considered by simply altering the chute profile. It should be noted that the triple profile results in a supplementary discharge angle of 33^o in the final cone section in addition to the true centre angle of the tilting chute. Therefore when a chute tilt angle of 30^o is selected for example, the material exits the final section of the chute at a true discharge angle of 63^o. (see figure 6)

In order to validate the material trajectory, a series of tests were carried out to ascertain the impact point for each material at the specified high and low stock line levels. For each of the three available materials, tests were undertaken varying the true centre angle of the distribution chute from 4^o to 38^o. For angles between 0^o and 4^o the chute configuration was seen to play little or no part in influencing the material trajectory. This characteristic is utilised for true centre charging for which the gimbal top is uniquely suited.

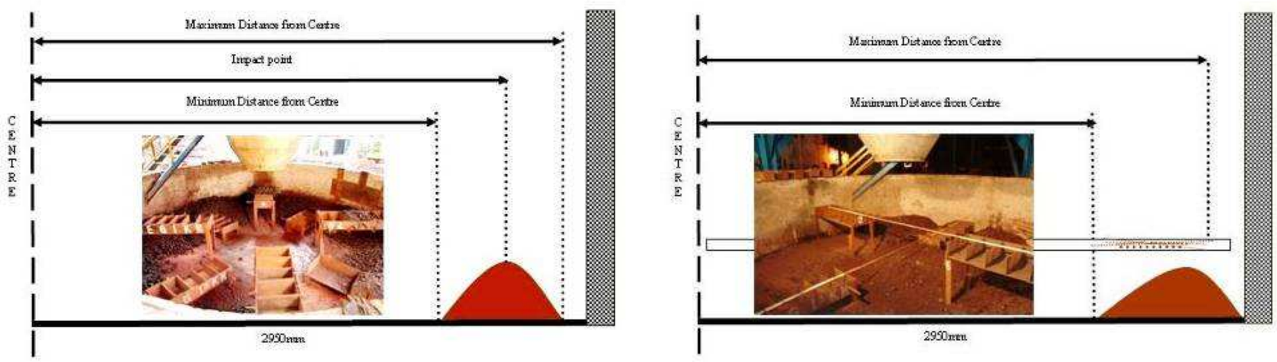


Figure 5: Impact Point Identification Techniques.

Two different techniques were employed to identify the impact point of the material. Firstly, for angles between 11^o and 38^o sample trays were used to collect discharged material and the impact point was taken as the point where the material peaked. Secondly, for angles between 4^o and 10^o target poles placed across the furnace throat area indicated the point of impact identified by the build up of material on the pole.

Summating the test data produced an accurate record of material trajectory versus tilt angle across the entire surface of the simulated blast furnace throat at the specified high and low stock line levels. This factual record of actual performance allowed comparison and calibration of previously theoretical expectations of discharge characteristics confirming the required settings for future furnace operation. In addition, the data will provide further confirmation of tilting chute performance within burden distribution models which are integral to the Siemens MT VAiron closed loop expert system.

When considering the trajectory data obtained from the tests the various unique characteristics of the conical tilting chute were noted when compared to conventional theoretical prediction methods and empirical data. As shown in figure 6 it can be seen that for the materials tested the recorded impact point was further from the furnace centre than predicted demonstrating the beneficial effects of the triple cone profile in terms of material trajectory.

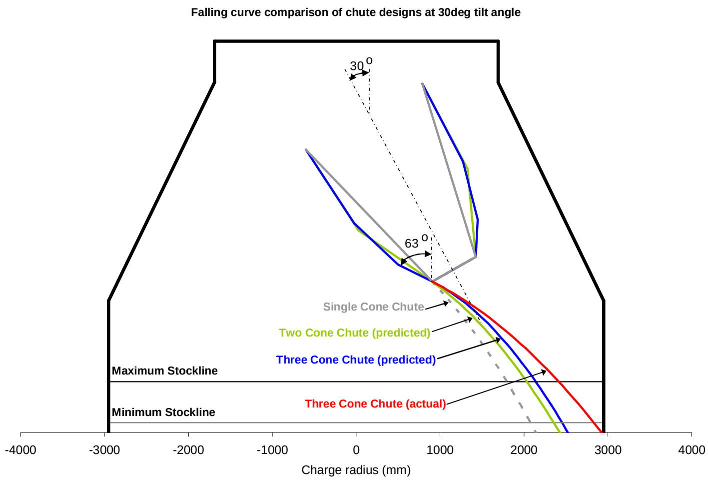
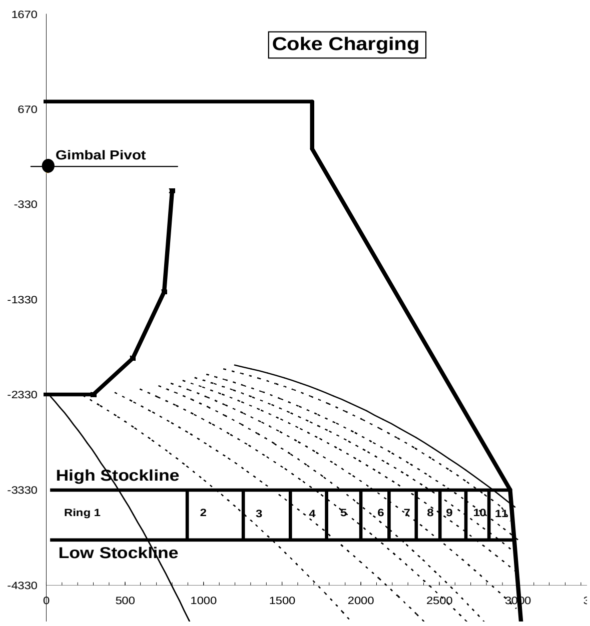


Figure 6: Comparison of Chute Trajectory

From the test data recorded the following conclusions were drawn with respect to material trajectory. Firstly, that for the known burden materials to be utilised in the future operation of 'C' blast furnace, the design and profile of the conical tilting chute selected will ensure that the discharged materials will strike the furnace throat at the highest stock line level. Secondly, the furnace charging system incorporating the innovative gimbal distributor is capable of providing complete coverage of the burden surface utilising conventional ring charging practices.

The charging characteristics of the Gimbal Top® charging system for 'C' blast furnace are shown in Figure 7 below.



Ring No.	Chute Tilt Angle ^{o}
1	7
2	11
3	14
4	17
5	21
6	24
7	25
8	28
9	29
10	32
11	34

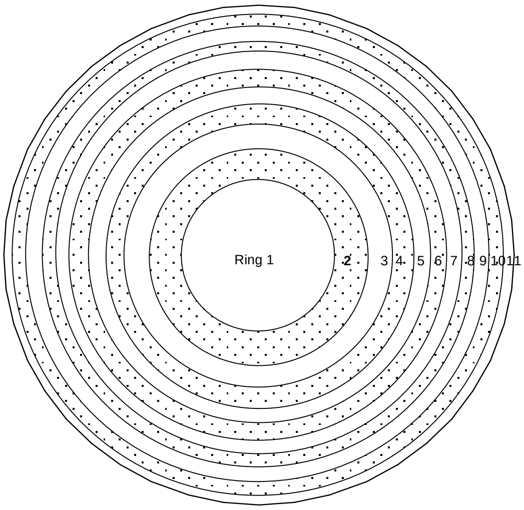
Figure 7: Falling Curve Characteristic – 'C' Blast Furnace, Tata Steel Ltd

MATERIAL DISTRIBUTION TESTING

As a world's first, the gimbal test facility at Jamshedpur offered Siemens MT and Tata Steel Ltd a unique opportunity to validate and document the distribution performance of the new Gimbal Top® blast furnace charging system. The aim of the distribution tests was to execute and demonstrate conventional furnace charging patterns including ring, centre, spot, segment or sector charging and Siemens MT spiral charging technique. Tests included the potential effects on distribution of the instantaneous changes in the rotational speed and or direction of the tilting chute possible with this innovative technology.

Ring Charging

Material profile analysis was carried out for Coke and Iron Ore to produce an understanding of the geometry of the rings being produced. Due to the limited quantity available from the material receiving hopper, to measure the profile of the material two sectors of 180^o were charged using different tilt angles. The analysis carried out adopted the conventional charging practice of eleven (11) rings dividing the furnace throat cross-section into equal areas to ensure complete coverage.



Position	Charge Radius m(ft)	Impact Point m(ft)	Tilt Angle Coke deg	Tilt Angle Ore deg
Ring 1	0.89	0.44	7	8
Ring 2	1.26	1.07	11	13
Ring 3	1.54	1.40	14	15
Ring 4	1.78	1.66	17	19
Ring 5	1.99	1.88	21	23
Ring 6	2.18	2.08	24	27
Ring 7	2.35	2.27	25	29
Ring 8	2.52	2.43	28	31
Ring 9	2.67	2.59	29	33
Ring 10	2.81	2.74	32	36
Ring 11	2.95	2.88	34	38

Figure 8: Conventional Ring Charging – Eleven Ring Throat Coverage

It should be noted that when documenting the necessary tilting angles to achieve the desired rings for furnace operation, the centre of each ring was considered for the necessary impact point. On studying the profiles created it was identified that for 'C' furnace operation the higher tilt angles would not be required in normal operation when charging the furnace to the low stock line level (0.5m below maximum). The remaining high angles can be utilised should it become necessary to charge material to the furnace walls.

When considering the intended charging practice for operation of 'C' blast furnace, a charging sequence of C/C/C/O/O/O single skip discharge will be adopted. Based upon the intention to achieve a complete two (2) ring discharge for the contents of each hopper three (3) designated angles were selected for each hopper charge identified from previous trajectory data.

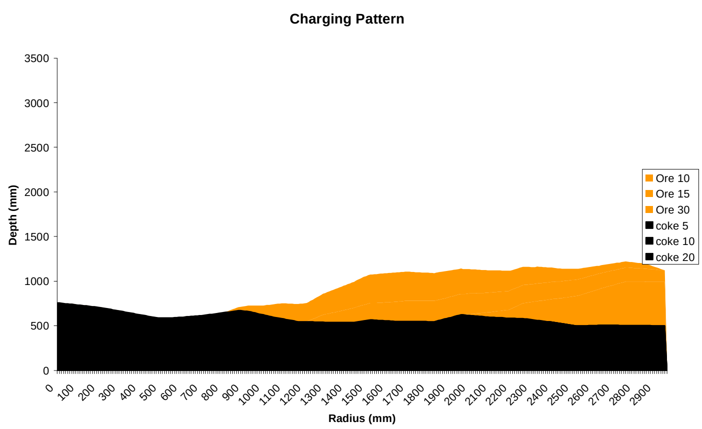


Figure 9: Suggested Charging Pattern Coke and Iron Ore

Figure 9 above depicts a charging pattern designed to provide coke at the centre of the furnace and iron ore to the outer wall. Charging pattern tests were undertaken

between the maximum stock line level 1m below and the lower stock line level 1.5m below the end of the distribution chute when vertical.
The collated data will be utilised to predict any necessary charging distribution patterns for levels up to 4m below the maximum stock line.

Spot Charging
Spot tests were carried out with each burden material coke, ore and sinter. The contents of the material hopper were placed at multiple locations across the furnace throat by redirecting the chute whilst opening and closing the material flow gate during discharge. The selected locations included the exact centre of the furnace utilised in modern charging practice for feeding of large coke. The unique flexibility of the gimbal mechanism is ideally suited to true centre charging by simply bringing the chute to the vertical above the furnace centre.

Figure 10: Spot Charging Tests

Sector (Segment) Charging

Sector charging is easily achievable with the gimbal top and a series of tests were conducted over the full range of rotation speeds to document the discharge performance for multiple segments at infinitely variable angles from rings 1 to 11. With the chutes unique ability to instantaneously reverse direction, material discharge can be achieved over the entire segment without interruption of the material flow providing precise accuracy within a designated sector.

Figure 11: Sector Charging Tests

Spiral Charging

Siemens MT patented spiral charging technology allows complete and even coverage of the furnace throat utilising the pre-described eleven (11) rings in a continuous spiral discharging a specified amount of material to selected rings. With known material discharge flow rates and precise modulating control of the material flow gate and tilting chute speed, preselected quantities of burden can be charged to the entire furnace stock line. On the completion of each discharge, re-calibration allows automatic adjustments of the flow gate and speed in preparation for the next spiral charge to improve system accuracy.
The pre-selected quantities of material to be discharged to charging ring are expressed as a percentage of the weight of material held in the material receiving hopper. This totally flexible charging method allows, as many or as few, rings to be selected with the discharge sequence executed in one seamless spiral. An example of the settings and results for one particular test are shown in figure 12 below. The even coverage of the furnace throat by the charge material can be clearly seen in the photograph.

Ring No.	1	2	3	4	5	6	7	8	9	10	11
Tilt Angle	5	7	9	11	14	17	20	23	26	30	34
Weight %	10	10	10	10	10	10	10	10	10	5	5

Figure 12: Throat coverage by Spiral Charge

As previously stated the operational test facility allowed manual control of the material flow gate and distribution chute via a PLC, therefore fully automated spiral charging was not undertaken during the test period. For the purpose of these operational tests spiral charging was undertaken utilizing pre-selected flow and rotational speeds to validate and check the functionality and performance of the gimbal mechanism when utilizing the well proven, patented software.

Wave Charging

On completion of the tests of conventional blast furnace charging techniques Siemens MT and Tata Steel Ltd took the opportunity to undertake a series of tests utilising the unique ‘Wave’ charging pattern. This unconventional yet innovative charging technique, utilising a pre-described reversing sinusoidal wave charging pattern, was developed by Siemens MT as a demonstration of one of an unlimited number of charging techniques that can be explored in the future exploiting the infinite potential of this exciting new technology development.

Figure 15: Wave Charging Tests

CONCLUSIONS

The test programme for the Gimbal Top® charging system was successfully completed by Siemens MT and Tata Steel Ltd in all respects and provided a clear demonstration of the flexibility and potential of this innovative charging system and its ability to achieve the necessary requirements of a modern furnace charging system. During the three month testing programme the following validation tests were completed and documented for Iron Ore, Sinter and Coke.

- Volume Flow Rates for the Material Flow Gate established
- Falling curves established
- Trajectories achieved for Furnace Throat at High and Low stock line levels
- Conventional charging patterns proven including Ring Percent and Spiral Charging
- Burden cross-section profiles established for a range of discharge rates
- Centre charging proven
- Segment charging proven

As the world's first Gimbal Top® blast furnace charging system, the opportunity to undergo full operational tests prior to final installation on the furnace, provided Siemens MT with a unique opportunity to demonstrate to the customer's operating and maintenance personnel the charging performance, operating control features and maintenance requirements of the equipment.
Registered Trade Marks: Gimbal Top, SGT3000, SGT6000
Patent No. W0 200 6056350

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