Design of Tundish Nozzles Alignment System for Multistrand Billet Casters in Continuous Casting Shop

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Abstract

The Continuous Casting Shop in Durgapur Steel Plant has two 6-strand billet casters where the molten steel is brought in ladles and poured into tundish. The nozzles in the tundish need to be accurately aligned with respect to the moulds for smooth casting. In the earlier system, the alignment stands had fixed templates. Alignment of tundish nozzles with respect to the fixed template was difficult to achieve due to the inaccurate placement of tundish in the alignment stands and geometrical incorrectness of the tundish holes. Also the cranes were engaged for lengthy durations for aligning the tundish in the alignment stands.

The new tundish nozzles alignment system comprises alignment mechanism having a movable template with precise guided motion, tundish holes alignment checking template for checking geometrical correctness of tundish holes, alignment fixtures and nozzle setting rods for aligning the nozzles and a PLC controlled hydraulic system for precise movement of alignment mechanism. The tundish alignment mechanism is a user friendly method to align the template with respect to tundish and place the nozzles accurately in the nozzle seating holes in the tundish during relining. It has also reduced the crane engagement time. This system has helped in increasing production by eliminating misalignment of the tundish nozzles.

Keywords: Tundish, Nozzles, Alignment, Alignment mechanism, Billet, Caster, Multistrand billet caster, Continuous Casting

1 Introduction

The Continuous Casting Shop in Durgapur Steel Plant has 2 nos. 6-strand billet casters where the molten steel is brought in ladles and is poured into tundish. Each tundish has 6 nos. of nozzles from where the molten steel is poured into the moulds for casting billets of section 100X100-125X125-150X150 sqmm. The nozzles in the tundish need to be accurately aligned with respect to the moulds for such section sizes. For this purpose, the Continuous Casting Shop at DSP has 6 nos. of tundish alignment stands for tundish preparation. In each of the tundishes, 6 nos. of nozzles are placed during relining. The alignment of tundish nozzles with respect to the fixed nozzle setting template was important for smooth casting. Any misalignment resulted in off centering of the nozzles with respect to mould, and thereby strand stoppage or eventual breakout of casting. The strand stoppages used to reduce the strand availability and increase the casting time. Casting sequence is aborted if strand availability goes below four. This resulted in lower productivity and required immediate attention.

2 Problem definition and solution

2.1 The old system of tundish nozzles alignment

In the earlier system (Fig.1), the alignment stands had fixed templates, which dimensionally match the moulds in the caster. The alignment of nozzles in the tundish is extremely important for smooth casting (Fig. 3). In the system with fixed template for aligning the tundish nozzles, the tundishes were placed on one of the six tundish alignment stands for relining. Due to a gap of approximately 20-25 mm in the guide for seating of tundish and also due to the geometrical incorrectness of the tundish, the tundish had to be maneuvered by the overhead crane to achieve an approximate alignment of the nozzle seat holes with respect to the fixed template. Then the refractory nozzle blocks were used to be placed in the nozzle seats. Here, the problem was further aggravated by nozzle blocks geometry (Fig. 2), which had a radius profile and a clearance of about 6-8 mm near the seating area with respect to the 100mm holes in the tundish. Any misalignment and inaccurate placement of tundish in the alignment stand resulted not only in linear misalignment of the nozzle block but also angular misalignment. The linear misalignment resulted in breakouts due to weak shell formation of cast billets on one side owing to uneven thermal load on moulds' primary cooling. The angular misalignment resulted in flickering of the metal stream and eventual strand stoppage. As there was no dedicated arrangement for movement of the tundish with respect to the template or vice versa in any of the six stands, and controlled movement of tundish was not possible by the overhead crane, it took a lot of time to approximately align the tundish with respect to template by lengthy engagement of crane to position the tundish on the stands. As a result misalignment used to occur due to inaccuracy and time constraint. Availability of the cranes for other activities of the shop was also reduced. This resulted in reduced productivity due to breakouts and strand stoppages as valuable production time was lost. The strand availability also got reduced. Accurate alignment of the tundish nozzles was need of the hour to overcome these problems.

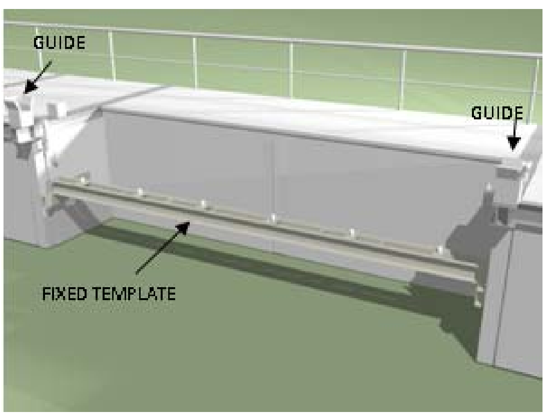


Fig 1: Fixed Template at Alignment Stand

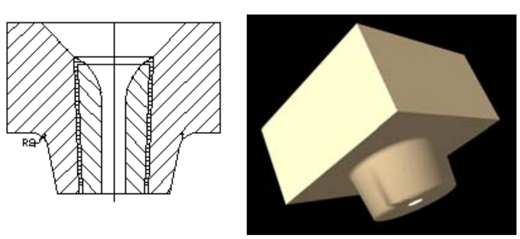


Fig 2: Tundish Nozzle

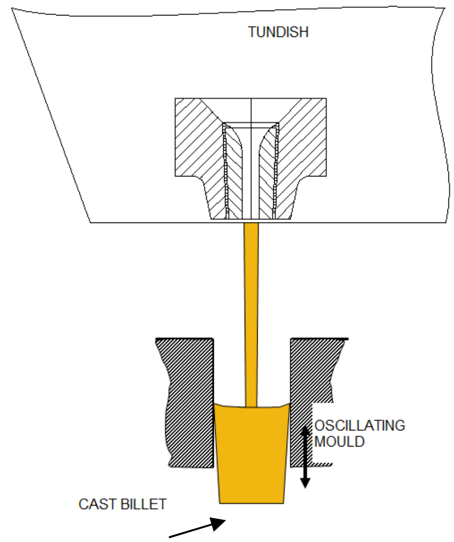


Fig 3: Billet Casting Process

2.2 The Solution

The problems of fixed template and deformed tundish holes geometry necessitated efforts for improving the tundish holes geometry and provision for precise relative motion between tundish and the template for accurate alignment of the nozzles. The option of moving the tundish with hydraulics was evaluated and ruled out as it would require bulky mechanism and higher size of actuators due to approximately 10 ton weight of the tundish and accuracy would not be achieved by this method. It was envisaged to move the template with respect to the tundish to achieve the alignment accuracy. If accurate alignment of all the six nozzles in a straight line was achieved at the alignment stand then the placement of tundish while casting can be done accurately by the tundish car which had a hydraulic mechanism for aligning the tundish with the moulds.

A new tundish nozzles alignment system was designed with a view to improve the tundish holes geometry, achieve accurate alignment of the nozzles in the tundish and reduce the crane engagement time for the alignment job. It was also required to devise the system keeping in view simplicity of the new procedure of alignment which would be understandable by the shop personnel handling the alignment job. This would ensure acceptability and quick adaptation of the system by the workforce. Care was also to be taken so that no additional manpower is required for carrying out the alignment job with the new system. The system controls were required to be operator friendly.

3 The new tundish alignment system

The new tundish nozzles alignment system (Fig. 4) comprises the following:

- An alignment mechanism with movable template
- Tundish holes alignment checking template
- Alignment fixtures
- Nozzle setting rods
- PLC controlled hydraulic power pack installed in an enclosure, and impulse piping and tubing
- Electrical panel with PLC and other electrical components, operator control panel and pendant type operator panel

3.1 The Alignment Mechanism

The Alignment mechanism consists of a beam, a template with nozzle setting blocks, sliding joints, and guides to provide guided translatory movement.

The mechanism has provision for continuous as well as inching movement of the template in two axes i.e. X-axis and Y-axis as well as rotational motion in the XY- plane i.e. horizontal plane. The hydraulic cylinders are mounted for providing the required motion to the mechanism.

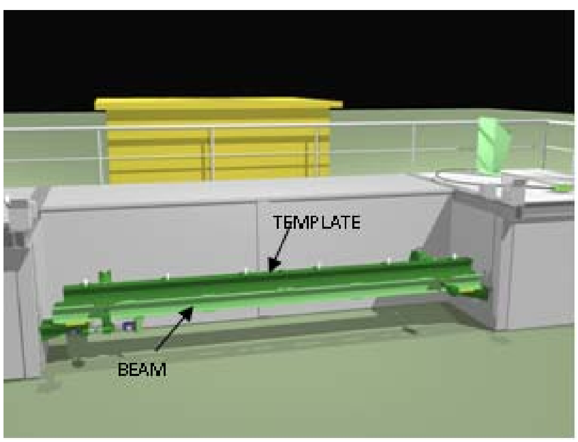


Fig.4: The New Alignment Mechanism with Movable Template

3.1.1 Salient Design Features of the Beam:

- It is a simply supported beam. The supporting mounting brackets are welded to the alignment stand and carry the load of the complete mechanism. The supports also act as a guided sliding joints with projection to match the grooved plate in mounting brackets for constraining the motion of the beam in X-direction
- The beam can make only X-direction motion which is guided by the grooved sliding plate combination.
- The beam has its own weight as uniformly distributed load and the weight of the template, hydraulic cylinders and their mounting brackets, and counterweights.
- The beam is fabricated with two steel channels in back to back configuration. Stiffeners have also been welded for flexural rigidity of the beam. The deflection of the beam at the centre of the simply supported beam was calculated by the formula according to double integration method [1]

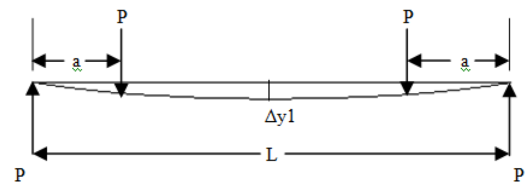


Fig 5: Deflection for Point Loads

$$\Delta y1 = \frac{PaL^2}{8EI} - \frac{Pa^3}{6EI} \quad \text{--------------------[1]}$$

and deflection due to uniformly distributed load w due to self weight of the beam by double integration method[1]

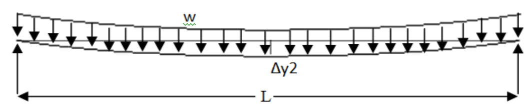


Fig 6: Deflection for Uniformly Distributed Load

$$\Delta y2 = \frac{5}{384} \times \frac{w \times L^4}{E \times I} \quad \text{--------------------[2]}$$

The total central deflection of the beam is the sum of the above two.

$$\Delta\, yb = \Delta y_1 + \Delta y_2 \quad \text{--------------------[3]}$$

Where E – Modulus of Elasticity and I – Area Moment of Inertia[4]. The total deflection at the center of the beam was found to be 1.9 mm, which is negligible.

- The beam has the corresponding brass plate with projection to match the grooved plate in mounting brackets for constraining the motion of the beam in X-direction.
- The brass plate on the beam is having longitudinal dimension larger than the brass plate on the bottom to cover the full stroke of motion of the hydraulic cylinder as well as protecting the sliding joint from ingress of falling refractory sand during relining of the tundish. For protection from dust the brass plate in beam is longer than that in the mounting brackets.
- The hydraulic cylinder, for movement of the mechanism in X-direction (Fig 7), is mounted on the

tundish stand and connected to the beam. The movement of the cylinder causes the beam along with the template move in the X-direction. The stroke length of the cylinder is 200 mm. The mechanism was capable of moving ±100mm from the central position where the piston rod is extended halfway.

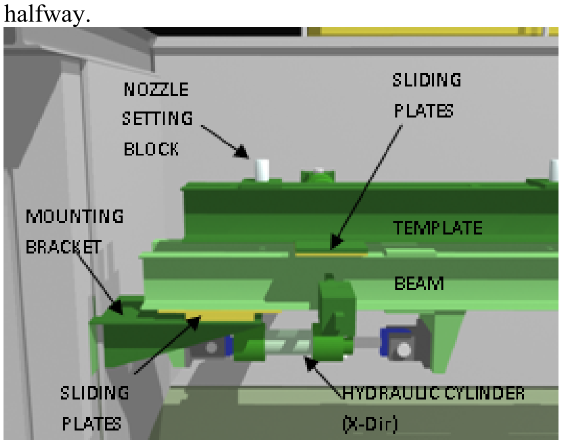


Fig 7: X-Direction Cylinder and Sliding Plates

- Force required to move the beam along with the template was calculated based on normal reactions at the supports.

  $F = \mu R_m = 2975$ N

  Where R_m = Total reaction of the mechanism including beam, template, cylinders and counter-weights which was about 11900 N, and coefficient of friction $\mu = 0.25$. This force is provided by the X-direction cylinder.

3.1.2 Salient Design Features of Template:

- Like the beam, the template is also a simply supported beam. The support also acts as sliding joints of having brass plates.
- The template can make only Y-direction motion and rotational motion in XY-plane with respect to the beam.
- The template is fabricated with two steel channels in back to back configuration. Stiffeners have also been welded for flexural rigidity. The template is designed for minimal (negligible) deflection at the centre with sufficient flexural rigidity. The template has its own weight acting as uniformly distributed load for calculating the central deflection by double integration method[1]

  $$\Delta yt = \frac{5}{384} \times \frac{w \times L^4}{E \times I} \quad \text{--------------------[4]}$$

  Where E – Modulus of Elasticity and I – Area Moment of Inertia[4]. The total central deflection of the template was found to be 0.485 mm which is negligible.
- The brass plate on the template is having longitudinal dimension larger than the matching brass plate on the beam to protect the sliding joint from ingress of falling refractory sand during relining of the tundish.
- The central guide and pin arrangement (Fig. 8) is made to constrain the motion of the template with respect to the beam only allowing Y-direction linear movement and rotational movement in XY-plane (i.e. Horizontal Plane). The template can move in X-direction only through the motion of the beam transmitted through the central guide and pin.
- The two hydraulic cylinders, for the linear movement of the template in Y-direction and rotational motion in XY-plane (Fig. 9), are mounted on the beam and connected to the template. The synchronized movement of both the cylinders forward or reverse direction makes the template to move in Y-direction forward or reverse respectively. The stroke length of the cylinders is 100 mm and the mechanism was capable of moving ±50mm from the central position where the piston rod is extended halfway. The cylinders have the pressure rating of 210 bar max.
- The reaction of the cylinder which is transmitted to the beam is constrained by the grooved sliding plate between the beam and mounting bracket on the alignment stand.

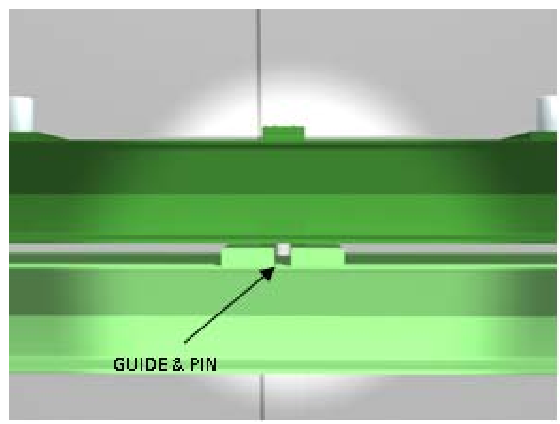


Fig 8: Central Guide and Pin Arrangement

- Force required to move the template was calculated based on normal reactions at the supports.

  $F = \mu R_t = 745.25$ N

  Where R_t = reaction of the template weight at one of the supports which was about 2981 N, and coefficient of friction $\mu = 0.25$. The Y-direction cylinder. This force is provided by each of the the Y-direction cylinders.

3.1.3 Positioning of the mechanism in the alignment stand

The positioning of the alignment mechanism in the alignment stand 1, where it was installed, was of utmost importance. All checks with regard to horizontal leveling of the mechanism were done and then the brackets were welded at proper elevation to maintain an appropriate clearance between tundish bottom plate and mechanism for ease of operation while alignment jobs are being carried out.

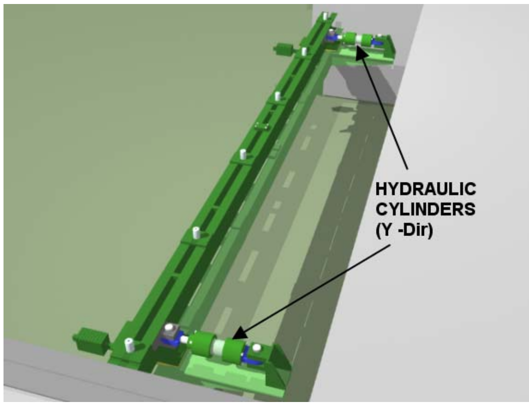


Fig 9: Y-direction Hydraulic Cylinders

3.1.4 Tundish Nozzles Hole Alignment Checking Template

The tundish nozzle holes alignment checking template (Fig. 10) has been fabricated and is used for checking the geometrical correctness of the 6 nos. tundish nozzle seating holes of 100 dia. at a distance of 1100mm in the tundish. The tundishes found out of alignment are sent for tundish bottom plate repair.

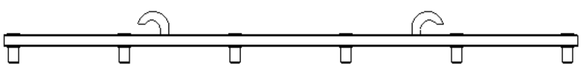
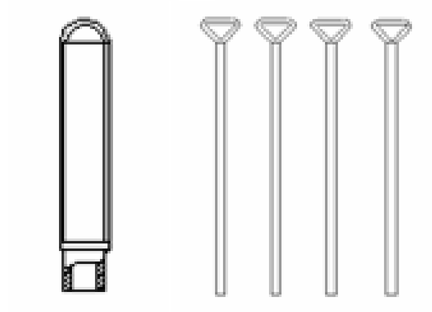


Fig 10: Tundish Holes Alignment Checking Template

3.1.5 Alignment Fixture and Nozzle Setting Rods

Six nos. fixtures have been fabricated from seamless pipe with appropriate tolerance to it to check the initial alignment of the template with respect to tundish (Fig. 11). The alignment of the template and the tundish holes is checked by the alignment fixtures and minor adjustments are done for accurately aligning the template with tundish by providing continuous as well as inching motion to the template. The alignment of the template with respect to the tundish nozzle hoes is checked by the alignment fixtures. All the six fixtures will match with the holes in the tundish and the corresponding nozzle setting blocks in the template when perfectly aligned with nozzle holes in the tundish.

Nozzle setting rods of 12mm, 13mm, 15mm, and 16mm diameter (Fig. 10) with appropriate tolerance have been provided for final alignment of nozzles. The nozzle setting blocks in the template have corresponding stepped hole for accurate alignment.



FIXTURE NOZZLE SETTING RODS

Fig 11: Alignment Fixture and Nozzle Setting Rods

The nozzle setting rod matches the bore in the nozzle and the stepped hole in the nozzle setting blocks to perfectly align the nozzles in the tundish at a distance of 1100 mm and all nozzles in a straight line.

3.1.6 The hydraulic power pack and PLC control panel

The PLC controlled hydraulic system (Fig. 12 & 13) provides controlled continuous as well as inching movement to the alignment mechanism, to align the template with respect to the tundish. The hydraulic power pack comprises a hydraulic oil reservoir, Motor, Pump & Air Cooled Oil Cooler, Double Acting Cylinders, Solenoid- operated directional valves, Flow control valves, Pilot operated Check Valves, Pressure Regulator, Pressure Line Filter, Return Line Filter, Accumulator, Impulse Tubing & Fittings. The power pack has one working and one standby motor and pump assemblies.

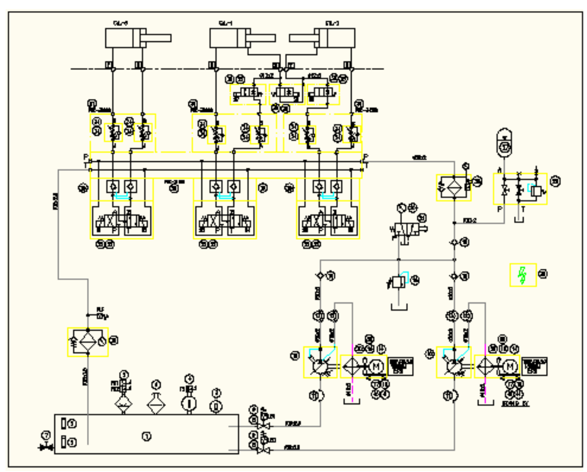


Fig 12: Hydraulic Circuit Diagram

The main control panel houses the PLC along with all the power and control circuit elements including DC power pack. The hydraulic power pack is operated through PLC based control logic for which the ladder logic diagram is uploaded in it. The ladder logic has been developed using Siemens Simatic programming software. The hydraulic power pack and its hydraulic circuit were designed keeping in consideration the linear movement of the mechanism in X and Y directions, and the rotary movement in XY-plane. The PLC ladder logic has been written for appropriate functioning of direction control valve as per the sequence, for desired operation of the hydraulic cylinders to achieve the linear and rotary motion of mechanism as required. The application area is dust prone due to refractory sands and exposure to heat due to proximity to the billet caster as well as its turn-over cooling bed, where the hot billets are naturally cooled while in transfer.

Fig 13: Hydraulic Power Pack and Main Electrical Panel

3.1.7 Operator Control Panels

The system can be operated from a local control station, which is installed on the tundish alignment stand platform near the alignment stand. A pendent type operator panel has also been provided for ease of operation, which can be taken near the tundish during tundish nozzles alignment jobs.

4 Alignment process

The tundish geometry checking is done to ascertain the correctness of the tundish holes and their rectification if required. The alignment mechanism is installed in the tundish alignment stand 1 and is utilized for alignment of the nozzles with respect to the template prior to relining and cold board fitting in the tundish.

The tundish is positioned on the tundish alignment stand by the EOT (Electric Overhead Travelling) crane and the crane is released immediately which results in increased crane availability for other jobs of the shop. The template in the alignment mechanism is imparted continuous as well as inching motion with respect to tundish, by the hydraulic power pack and cylinders, according to the requirement to align the template accurately with the nozzle holes in the tundish for accurate placement of nozzles in the tundish. The final nozzle placement is done with the help of nozzle setting rods.

The flow chart for alignment of nozzles by the device to align tundish nozzles is as follows:

1) Check the tundish with the tundish holes alignment checking template for geometrical correctness of the tundish nozzle holes (Fig. 14). All the defects in the tundish holes i.e. longitudinal and sidewise misalignment, hole diameter distortion are detected with this operation. The tundishes with any such defect can be sent for rectification. The nozzle holes diameter can also be checked with the alignment fixture at the time of rectification for a correct diameter of 100 mm. This job can be done intermittently to check the tundishes.

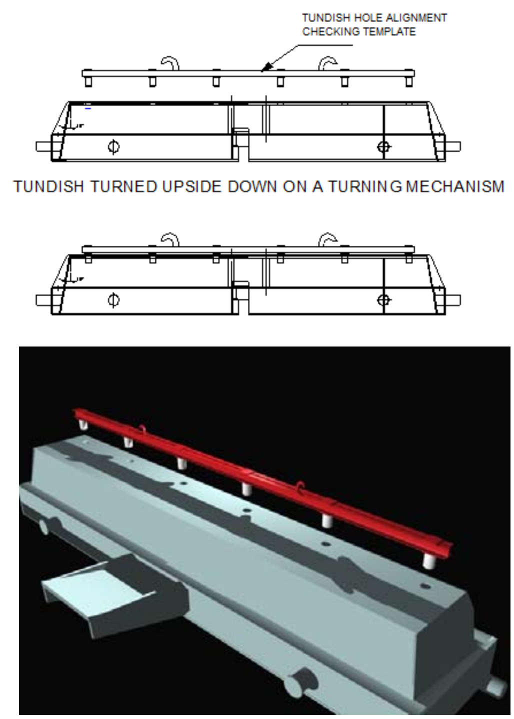


Fig 14: Tundish Hole Geometry & Alignment Checking

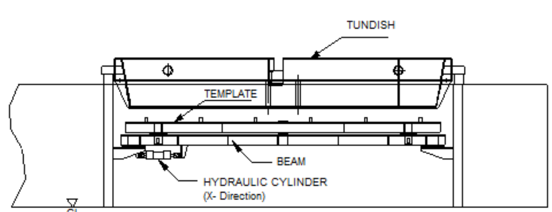


Fig 15: Tundish placed on Alignment Stand

2) The tundishes which are found alright and the rectified tundishes, which are used for casting, are placed by the Electric Overhead Traveling Cranes on tundish alignment stand which is having the device for alignment of tundish nozzles (Fig. 15) and the crane is released immediately.

STEP 3: The hydraulic unit is turned on.

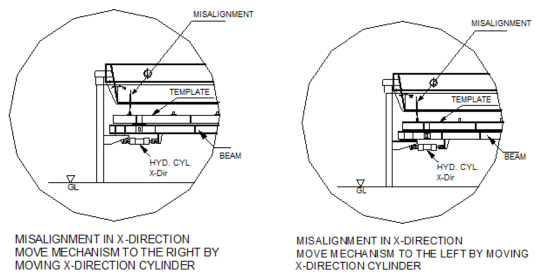


Fig 16: Alignment in X-direction

4) The template is aligned with the tundish by inching movement imparted by the hydraulic system in X-direction, Y-direction and XY-plane (horizontal plane). (Fig 16 & 17)

5) The alignment of the template with the tundish is checked by the alignment fixtures. (Fig. 18)

6) Repeat step 4 to step 5 till satisfactory accuracy is achieved. Any minor adjustment is done by inching movement of the template and checking with the alignment fixture. The alignment of template with respect to the tundish is achieved when all the six alignment fixtures perfectly match the tundish holes and the outer diameter of the nozzle setting blocks on the template.

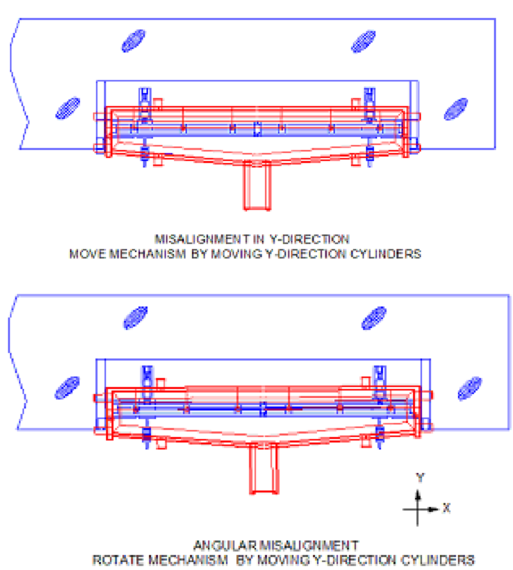


Fig 17: Alignment in Y-direction and XY-Plane

7) The nozzles are aligned with respect to nozzle setting blocks on the template with the help of the nozzle setting rods and final nozzle placement in the tundish is done. (Fig. 19)

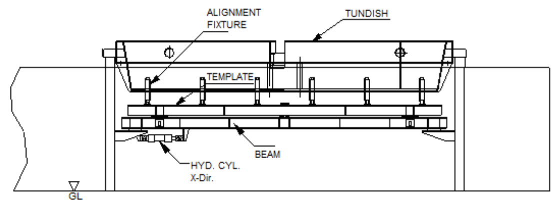


Fig 18: Checking alignment of template with tundish

8) After the alignment job the hydraulic unit is turned off.

After the alignment of nozzles, the refractory lining and cold board fitting in the tundish is done.

The system is designed keeping in view the application area which is dust prone and exposed to heat. The system is a simple and operator friendly system with all the controls conveniently available to the operator for controlling the movement of the alignment template very precisely for fast and accurate alignment of the nozzles.

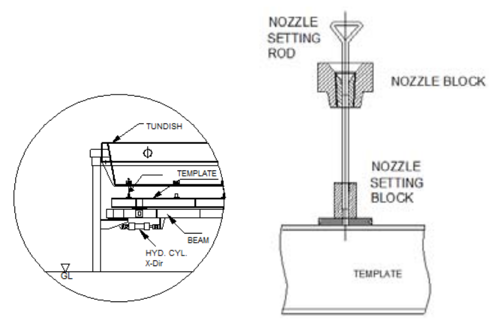


Fig 19: Final alignment of nozzles in tundish w.r.t. template

The entire routine of aligning the nozzle blocks in the tundish, which is geometrically correct, takes about 5 minutes. The system has resulted in accurate alignment of tundish nozzles.

5 Conclusions

The system was commissioned in September 2004 and has been in continuous operation till date. The tundish alignment mechanism has provided a user-friendly method to align the template accurately with the nozzle holes in the tundish for accurate placement of nozzles in the tundish. The system has helped in increasing production by eliminating misalignment of the tundish nozzle.

Average strand availability had increased from 5.5 to 5.6 or higher. Strand stoppage and breakouts due to misalignment of tundish nozzles have been eliminated. The entire alignment process has become less time consuming as the crane engagement time has been reduced from 1 hour to 15 minutes and the process of alignment of nozzles in the tundish takes about 5 minutes. This has resulted in increased availability of the overhead crane for other jobs in the shop. There is no requirement of additional manpower for the system. The tundish nozzles alignment system has been granted patent in 2009.

Fig 20: Tundish Alignment Mechanism

The following charts show the improvement in the strand availability and sequence rate before and after the introduction of the innovation.

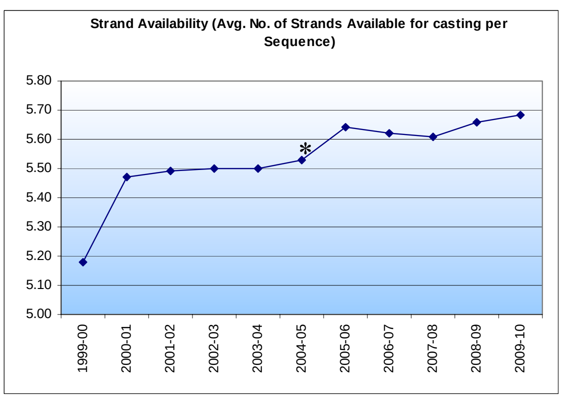


Fig 21: Strand Availability

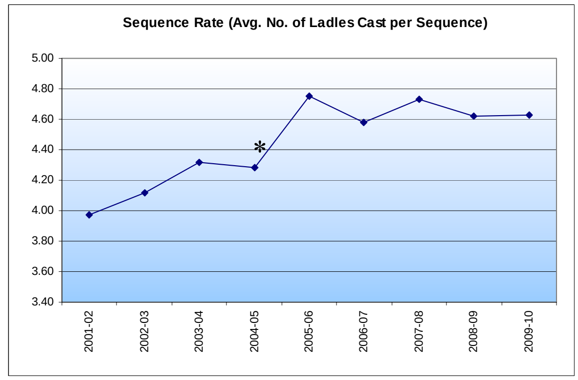


Fig 23: Sequence Rate

[*System was commissioned in September 2004]

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References

[1] W. H. Nash, "Strength of Materials", McGraw Hill Publications, New York, 1988

[2] "Hydraulics, Basic Principles and Components", Bosch Rexroth AG

[3] "Hydraulics. Theory and Applications", Bosch Rexroth AG

[4] R. Agor, "Steel Tables", Birla Publications, Delhi