Busbar Integrity in Potline Tunnels in EGA Jebel Ali Smelter

Ghalib Alfalasi[1], Ahmad Aljawhari[2] and Sudip Ghosh[3]
1. Senior Manager – Operations Support Reduction Midstream
2. Superintendent – Maintenance Midstream
3. Manager – Capital Projects Upstream
Emirates Global Aluminium (EGA), Jebel Ali, United Arab Emirates
Corresponding author: galfalasi@ega.ae

Abstract

Emirates Global Aluminium (EGA) Jebel Ali operates seven potlines with six different pot technologies. Each potline consists of sections of pots and busbar linkages, connecting these sections. The linkages consist of passageways between pot sections, end of potline crossovers, emergency crossovers and connections from end pots to the rectifiers. All these linkages are installed in tunnels, from simple to complex, below passageways or roads. All are equipped with powerful industrial cooling fans in different configurations. The tunnels and the fans were designed with traditional engineering practices at the time of potline construction without the aid of computational fluid dynamics (CFD) which was not yet available. Over time EGA Jebel Ali increased amperage in all potlines considerably and this increased the thermal load in the tunnels.

The largest amperage increase from 250 kA to 480 kA was in Potline 5 Eagle Section where five demonstration cells of four different technologies have been built since 1998: CD26, DX, DX+ and DX+ Ultra. The busbar linkages to Eagle Section are in a system of complex tunnels. With the increased thermal load in the tunnels, the existing cooling became inadequate and in March 2021 the supply circuit of the Eagle pots was cut off by local busbar melting and the pots had to be shut down. Since then, the tunnels and busbars have been rebuilt, and tunnel cooling was optimized with CFD simulations, for safe operation of DX+ Ultra Eagle pots at 500 kA.

Following the Eagle incident, Jebel Ali Busbar Integrity Project was launched with the aim of providing safe operation of busbars in the tunnels of all the potlines at planned amperage increase. The project consisted of systematic openings of the busbar tunnels at strategic locations, documentation of any damage, monitoring of busbar and air temperatures, fan evaluation and CFD simulation of all tunnels, accompanied by special measurements for CFD model validation. The cooling system configurations were optimised with CFD simulations of the tunnels.

This paper describes practical investigations of the busbar tunnels in EGA Jebel Ali, as well as examples of corrective actions for busbar integrity and safe future operation of potlines.

Keywords: Potline busbar linkages, Cooling of busbar tunnels, Industrial cooling fans, CFD simulation of busbar tunnels, Continuous monitoring of busbar temperatures.

1. Introduction

EGA is the largest industrial company in the UAE outside oil and gas. EGA operates aluminium smelters at Jebel Ali in Dubai and at Al Taweelah in Abu Dhabi, with a combined production of 2.501 Mt of cast metal in 2021, using EGA's own cell technologies. The smelter in Jebel Ali has seven potlines operating six cell technologies: CD20, D20, D20+, D18+, DX and DX+ Ultra, which produced 1.056 Mt of cast metal in 2021. The smelter in Al Taweelah has three potlines operating three technologies: DX in potlines 1 and 2, DX+ in Potline 3 and DX+ Ultra in the recent extension of Potline 3. The journey from a modest beginning in 1979 to a mega smelter happened with potline expansions and amperage increase [1].

In Jebel Ali smelter (Figure 1), each potline consists of sections of pots and busbar linkages, connecting these sections. The linkages consist of passageways between pot sections, end-of-potline crossovers, emergency crossovers and connections from end pots to the rectifiers. All these linkages are installed in tunnels, from simple to complex, below the potline passageways or roads. The most complex system of linkages is in Potline 9 at the rectifier end, shown in Figure 2. Another complex system is Eagle Section of Potline 5 (Figure 3), where five demonstration cells are installed, and are fed by the current from Potline 5 and the booster circuit. All tunnels are equipped with powerful industrial cooling fans in different configurations; altogether there are 131 fans in Jebel Ali smelter. The tunnels and the fans were designed with traditional engineering practices at the time of potline construction without the aid of Computational Fluid Dynamics (CFD) which was not yet available.

Figure 1. EGA Jebel Ali smelter.

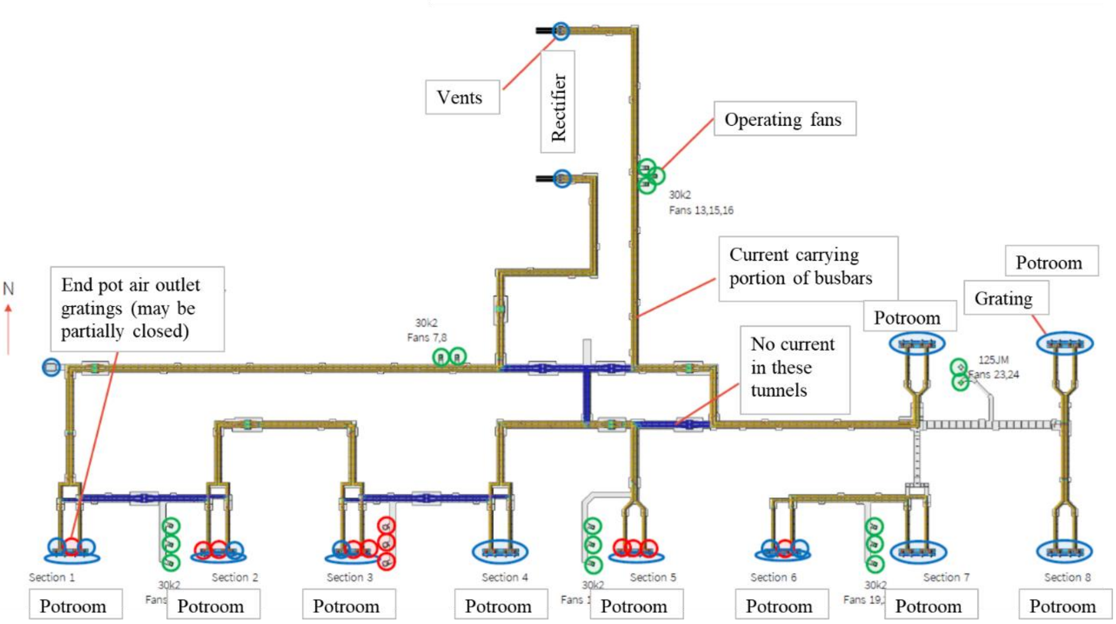

Figure 2. System of busbar tunnels in Potline 9, which has 10 potrooms (modified from [2]).

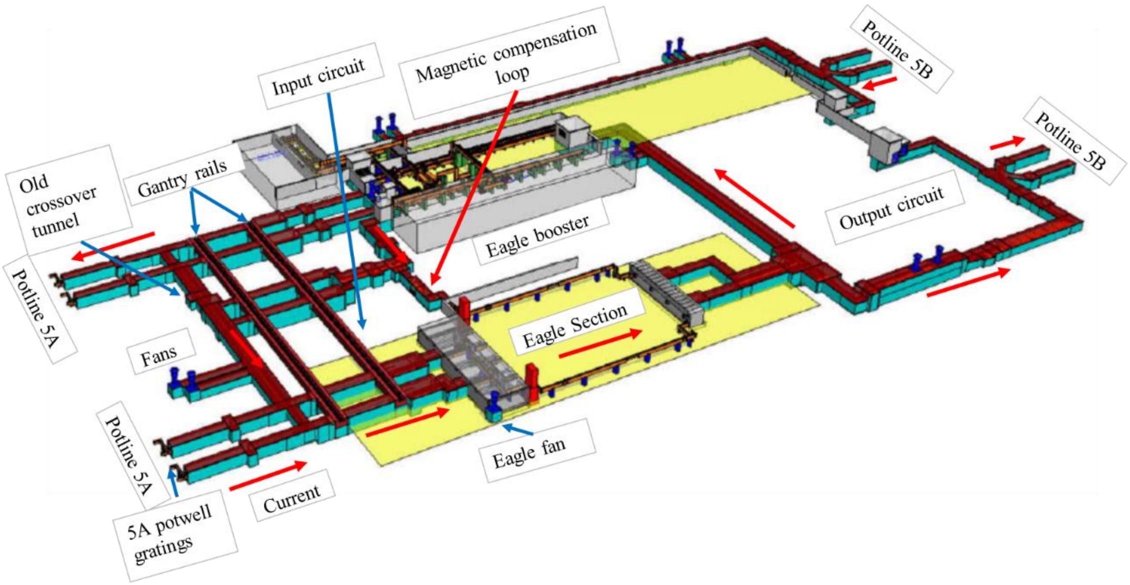

Figure 3. The system of busbar tunnels in Eagle Section of Potline 5 [2].

Over time, EGA Jebel Ali increased amperage in all potlines considerably and this increased the thermal load in the tunnels. Table 1 gives amperage increase in the potlines.

The largest amperage increase from 250 kA to 480 kA was in Potline 5 Eagle Section where five demonstration pots of four different technologies have been built since 1998: CD26 (1998-2005), DX (2005-2010), DX+ (2010-2014) and DX+ Ultra (2014-now). The busbar linkages to Eagle Section are in a system of complex tunnels, shown in Figure 3. With the increased thermal load in the tunnels, the existing cooling became inadequate and in March 2021 the current supply circuit of the Eagle pots was cut off by local busbar melting in the two supply tunnels and Eagle pots had to be shut down. Since then, the tunnels and busbars have been rebuilt, and tunnel cooling was optimized with CFD simulations, for safe operation of DX+ Ultra Eagle pots at 500 kA, started in March 2022. This incident was subject to a separate investigation, described in Section 3.

Table 1. EGA Jebel Ali pot technologies and amperages.

Potline	Start-up	Technology	Original	June 2022	Future plan
1	1979	P69, D18	150, 205 max	No more	No more
3	1981	P69, D18	150, 205 max	No more	No more
1	2016	D18+	205	238	245
3	2017	D18+	205	240	245
5	1996	CD20	200	244	269
Eagle, 5 pots	1998-2005	CD26	250, 280 max	No more	No more
pots	2005-2010	DX	320, 350 max	No more	No more
Eagle, 5 cells	2010-2014	DX+	420, 460 max	No more	No more
Eagle, 5 cells	2014-2021	DX+ Ultra, G1	440, 480 max	No more	No more
Eagle	2022-now	DX+ Ultra, G2	500	500	500
5B, 32 cells	2007, 2008	D20, D20+	225	267	275
6	1999	CD20	200	243	269
7	2005 (7A) - 2006 (7B)	D20	225	270	275
8, 44 cells	2008	DX	340	429	437
9	2003 (9A) - 2006 (9B)	D20	225	264	275

2. Jebel Ali Busbar Integrity Project

2.1 Objectives and Scope

Following the Eagle incident, Jebel Ali Busbar Integrity Project was launched with the aim of providing safe operation of busbars in the tunnels of all the potlines at current amperage and planned amperage increase shown in Table 1. The amperage increase was put on hold until such time the busbar integrity in the tunnels was assured.

Detailed key objectives of this project were:

- To evaluate current condition of the tunnels and busbars with visual inspections after removal of selected tunnel slabs.
- To evaluate busbar cooling of all the tunnel networks with Computational Fluid Dynamics (CFD) simulations, identify cooling problems and propose improvements [2].
- To build 3D models of the tunnels for easy future maintenance and modifications. These were also the used for CFD model geometry.
- To facilitate and develop busbar condition monitoring systems for future busbar integrity.
- Provide easy accessibility to critical areas of the busbar tunnels in future.
- Develop a system of periodic inspections and maintenance of busbars in future.
- To extend busbar life indefinitely.

The scope of the project consisted of:

- Onsite inspection and reporting:
    - Identification and opening of selected slabs for inspection of tunnels.
    - Visual, thermography and thermocouple assessment of busbar temperatures.
- Compilation of locations with defects.
- Analysis of:

    - Root cause of these defects,
    - Mitigation of root cause to prevent future incidents,
    - Reinstatement method.
- Replacement of concrete slabs with an improved design to facilitate easier lifting in the future.
- Installation of busbar and tunnel ventilation and busbar temperature monitoring with automatic recording and alarms.
- Establishing periodic verification and maintenance of the system, including cooling fans.
- Automation and integration of the signals to SCADA.

2.2 Identification and Opening of Tunnel Slabs for Inspection

The project consisted of systematic openings of the busbar tunnels at strategic locations, documentation of any damage, installation of monitoring of busbar and air temperatures, and in a few places, measurement of air flow rate. Altogether 315 places were opened on top of the tunnels. The criterion for choosing the place where to open the slabs was based on the existing drawings of the tunnels. The interest was in welds, flexibles and busbar corners. Once the slabs were open:

- The condition of the welds and of the flexibles was inspected. Photos and thermographic pictures were taken. A list of observations at every site was recorded.
- Busbar supports and epoxy grout on top of the supports were checked,
- Concrete walls and covers were checked for any deterioration or cracking,
- Water presence, if any, was identified and the source searched for.

In all places, the busbars were in good conditions, no broken or poor welds were found, and no flexibles were broken or damaged. No repair was required on the busbars.

2.3 Abnormalities and Damages Found

Busbars Displaced by Electromagnetic Forces

In crossover busbars between two potrooms, there are two packs of busbars carrying current in the same direction. In each pack, the busbars are separated and held in position by welded tie-bars on the top, whose role is to keep the busbars separated and at the same electrical potential which assures equal currents in each busbar. In the central section of the crossover, the two packs of busbars are in the same tunnel, which by design were separated by 350 mm, but no separators were installed. The result was the displacement of the two packs towards each other by attractive electromagnetic forces as shown in Figure 4. It appears that this happened all along the tunnels, starting at the first flexible. The only consequence of this is a reduction in cooling of the central two busbars. It is estimated that the busbar temperature in the two busbars in contact is less than 10 °C higher than if the busbars were separated. This abnormality does not affect the safe operation of the busbars, particularly since the tie-bars were not broken anywhere, and it was therefore decided to leave the busbars as they are. The flexibles were observed to be flattened on one side, but retained sufficient space for expansion; none were damaged (Figure 4, left).

In the approach to the end pot in all potrooms, the two crossover busbars are in separate tunnels as shown in Figure 3, at the distance of 6 m between busbar centrelines. The same situation is in the potroom passageways. On a few end crossovers, the electromagnetic force was strong enough to pull the busbar packs towards each other but they were retained by the inner wall of each tunnel as shown in Figure 4. In this case, too, the displacement does not affect safe operation and the busbars were left in displaced position.

The force between two conductors carrying current in the same direction is attractive, for currents in the opposite direction, it is repulsive. When the busbars are not far apart with respect to their height and width, the force per unit length of the busbar is given by Equation (6.1):

$$\frac{F}{L} = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{d} = 2 \times 10^{-7} I_1 I_2 \frac{k}{d} \tag{1}$$

where:

F/L	Force per meter of bars, N/m
μ_0	Permeability of vacuum = 4π x 10^{-7} Vs/Am
I_1	Current in 1st busbar, A
I_2	Current in 2nd busbar, A
d	Distance between centreline of busbars, m
k	Correction factor for rectangular busbar shape and distance between busbars [3].

For the force between two busbar packs in consideration d >> busbar height or width, k ≈ 1, but for the attraction force between the busbars of a busbars in a pack, k = 0.5-0.9. For the busbar packs in the same tunnel, carrying 125 kA each at centreline distance of 0.54 m, the electromagnetic force between them is 5.8 kN/m by design and 8.9 kN/m when they are pulled together as shown in Figure 4. For busbars in separate tunnels at 6 m from each other, the force is 0.5 kN/m. This was still sufficient to displace the busbars as shown in Figure 4, right, since the flexibles at each end do not present much resistance against lateral displacement.

Figure 4. Busbars displaced by attractive electromagnetic forces; left - 2 packs in one tunnel, right – 2 packs in different tunnels. Tie-bars were not damaged.

Damage on Busbar Supports

Busbar supports have two roles:

- Mechanical support to keep them off the floor
- Electrical insulation from ground, which is provided by a layer of epoxy grout on top of the support.

Observations were made on the sides of the busbars. Typical damage is shown in Figure 5. There could be cracked epoxy grout, cracked concrete or detachment of epoxy grout from the concrete below. In most cases, it looks that the damage is only peripheral and will not be a risk for future operation since the busbars in a pack are tied together and act as a whole block. For the damage to be significant the whole length of the support would have to be damaged, but this evidence was not found. Nevertheless, it was recommended to evaluate possible repairs and to examine the supports below the busbars with a remote camera before any repair is undertaken. Of course, some supports will be repaired in the side channels, where the access is possible.

Figure 5. Typical damage to the busbar supports. Left: detachment of epoxy grout; this does not need repair. Right: Cracks that were recommended for repair, even though they do not compromise busbar integrity.

Damage to the Tunnel Walls and Cover Slabs

The most vulnerable parts of the tunnel concrete are cover slabs and the upper parts of the sidewalls because these are at the highest temperature. Most cover slabs were damaged by excavation, but some were also cracked by heat. All these had to be replaced with new ones, which were designed so that they can be easily opened in the future. Most sidewalls were also not affected or very little and were strong enough to hold the new slabs (Figure 6). In a few cases, however, the damage to the cover slabs and sidewalls was substantial: the cover slabs were heavily cracked or disintegrated when being removed. In two tunnels, the sidewalls were also heavily cracked; an example is shown in Figure 7. In these two cases the entire tunnels were rebuilt, which required an installation of the busbar bypass and the removal of the existing busbars in order to continue the potline operation.

Figure 6. Tunnel sidewalls not damaged. Left – Potline 9, right – Potline 7 long tunnel. Both show busbar temperature monitoring thermocouples discussed later.

Figure 7. Damaged tunnel walls in Potline 6 south below the gantry road, which had to be rebuilt.

3. Eagle Incident

Eagle busbar circuit and tunnel system is shown in Figure 3. On 26 March 2021, the current supply circuit of the Eagle pots was cut off in the two supply tunnels by local busbar melting and Eagle pots had to be shut down. Potline 5 in which Eagle is situated as shown in Figure 3 was connected through the bypass between Potlines 5A and 5B behind Eagle booster, which had been built for the purpose, and the potline was successfully restarted. During the incident, Eagle magnetic compensation loop, which forms a parallel circuit to the Eagle booster circuit, suddenly carried all Eagle current of 480 kA for a while and, at tap end of the pots, was thrown off the supports onto the ground far away from the pots by electromagnetic forces, which were repulsive on the tap end of the pots. The whole event lasted about 5 minutes before the power was shut down.

Initial investigation by opening the west tunnel indicated by the smoke during the incident showed melted busbars in the west tunnel, whereas at the same position, the busbars in the east tunnel were not affected at all as shown in Figure 8. Following this, the busbar tunnels were open in several other places and no indication of any busbar or tunnel damage was found. The tunnels below the gantry road were opened much later because all the traffic on the road above had to stopped and it was found out that the busbars in the east tunnel were cut off in the welds at the end of the gantry tunnel, before rising through the narrow bottleneck as indicated in Figure 8. Figure 9 shows the condition of the busbars and the tunnel ceiling in east tunnel. At this opening, we concluded that the busbars were cut off first in the east tunnel due to high temperature, caused by poor ventilation, exacerbated by debris from the tunnel ceiling and poor weld quality at that location. At that moment, all the potline current minus compensation loop current was flowing through the west-tunnel busbars, which melted with a big electric arc and smoke. This pushed full Eagle current of 480 kA into the compensation loop, which was instantly displaced as described above.

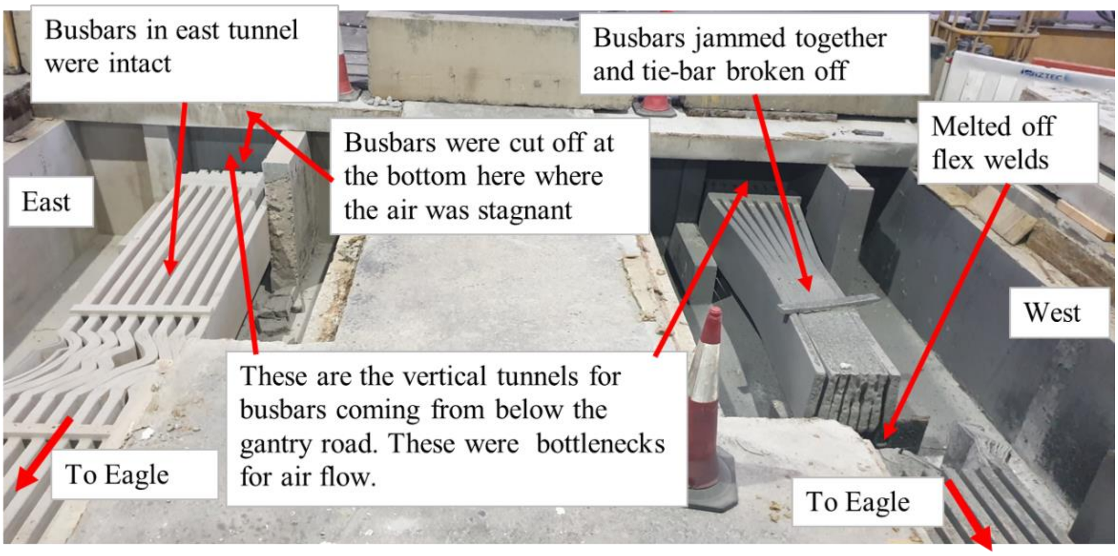

Figure 8. Triggering event of Eagle incident.

Figure 9. Root cause of Eagle incident. Left: busbar cut off in east tunnel. This was the first event. Right: lower ceiling (of double ceiling) decomposed and collapsed onto the busbars in east tunnel.

During a few months when it was not known that the busbar in east tunnel was cut off, calculations were made to explain the incident. By reverse engineering, starting from the position of the compensation loop at tap end, the electromagnetic force required for the loop displacement was calculated and from the force it was calculated that more than 400 kA had to flow in the loop. This was confirmed later as described above. In fact, 480 kA was flowing in the loop when it was displaced. With this current, the electromagnetic force on the loop was 7 kN/m, which gave it a horizontal acceleration of 1.7 times the gravity.

It was also calculated that no electrical pulse produced by the electrical arc in the west tunnel would be able to send such a high current in the loop. In fact, a pulse of only +15 kA, -53 kA was recorded in the booster circuit on the current monitoring systems during the incident. Calculations show that in steady state, the compensation loop carried only 65 kA when busbars were still connected in only one tunnel, which is not even twice the normal loop current. It was not possible to explain what happened if the busbars were cut only in one tunnel as it was assumed initially.

As the solution for safe operation in the future the following actions were taken:
Both, east and west tunnels below the gantry road supplying Eagle current were enlarged and completely rebuilt,

- The busbar cross-section was increased by 25 %, thus reducing the current density from 58 A/cm^2 at 480 kA to 48 A/cm^2 at 500 kA
- The ventilation of Eagle busbar circuit was optimized as described in [2],
- The compensation loop was rebuilt as before, but with much stronger lateral supports. Continuous current monitoring with LKAT Hall sensor device from Dynamp was installed and a high-speed, high-power ABB circuit breaker was installed in the loop to switch it off, should the current, measured by LKAT, increase beyond a specified limit.
- Eagle pots were restarted with a new design in March 2022 at 500 kA.

4. CFD Simulation of the Tunnels and Model Validation.

It was clear from the start that busbar cooling in these complex busbar tunnels cannot be evaluated nor improved otherwise but with full Computational Fluid Dynamics (CFD) models of air flow and busbar temperature calculations. Modelling was undertaken for Eagle area first and was extended to the whole plant later [2]. All different tunnel configurations were modelled and ventilation improvements recommended if required. The models were validated with busbar temperature measurements in many tunnels and air flow measurements in two locations. The validation concluded that the models overpredicted the busbar temperature by about 10 °C, which leads to conservative conclusions for busbar ventilation [2]. The recommended improvements will guarantee that all the tunnels will be adequately cooled if the fans are continuously working as proposed in terms of the number of fans per tunnel or system of tunnels and openings for air exit.

4.1 Air Flowrate Measurements and Cooling Fan Monitoring

4.1.1 Airflow Measurements

Air flow rate in the tunnels was measured using a Pitot tube [4]. This requires local velocity measurements in many points over the tunnel cross-section, because the air flow distribution is not uniform over the cross-section of the tunnel, primarily due to the busbars, supports and tunnel geometry. Also, in Eagle Section, the measurement locations were not far from flow disturbances upstream and downstream, being measured at the tunnel outlets into the basement [4]. The velocity is determined from differential pressure, measured by Pitot tube, according to Equation (3). Average velocity over an area is calculated, then volumetric and mass flow rate with Equations (3) and (4).

$$v = \sqrt{\frac{2\Delta p}{\rho}} \tag{2}$$

$$\phi_V = vA \tag{3}$$

$$\phi_m = \rho \phi_V \tag{4}$$

where:

v	Air velocity, m/s
Δp	Differential pressure, measured with Pitot tube, Pa
ρ	Air density, kg/m^3.
ϕ_V	Volumetric flowrate, m^3/s
ϕ_m	Mass flowrate, kg/s
A	Area of the tunnel cross-section, m^2

Air density is a function of temperature, which was measured. The tunnel air flow cross-section is complex because of the busbars. The whole area for velocity averages was divided into: a) above busbars, b) sides of busbars and c) between busbars. Table 2 gives the air flows for Eagle tunnels at the exit of the two input tunnels towards Eagle Section and at exit to Pot 121 of Potline 5. In each Eagle tunnel, Pitot tube was placed in 90 positions across the tunnel cross-section free for air flow, because of the complexity of the flow due to busbars. In Potline 5 gratings, 4 positions were measured in each gap.

The optimal amount of partial closure of pot-well gratings at Pot 121 of Potline 5A was determined with these measurements and also the air deflector size and inclination of Eagle fan at entrance into the basement upstream of Eagle pots. Four 50 mm wide, 1000 mm long gaps are sufficient for the two tunnel outlets at Pot 121. In another measurement the gratings at Pot 121 were completely open; in this case 12.3 kg/s was escaping through these gratings and only 4.2 kg/s went through each Eagle tunnel. High air flow rate in the tunnels towards Pot 121 is not required, which is witnessed by quite low busbar temperatures at that location, shown in Figure 10.

These data were also used for CFD model validation [2].

Table 2. Measured airflow and fan static pressure in Eagle input tunnels

Date of measurement	25/03/2022		12/05/2022	
Amperage in Eagle pots (kA)	500		500	
Number of fans working at PL 5A	2		2	
Average static pressure in Fan 1, 5A	504		522	
Average static pressure in Fan 2, 5A	594		582	
Eagle fan	Working with deflector		Working with deflector	
Average static pressure in Eagle fan	380		381	
Louver at booster rectifier	Open		Open	
Outside air temperature (°C)	26		35	
Gratings at Pot 121, Potline 5				
Gratings at Pot 121, Potline 5, open	4 gaps of 75 mm		4 gaps of 50 mm	
Air temperature in the tunnel (°C)	33		44	
Volumetric flowrate (m^3/s)	3.6		1.7	
Mass flowrate (kg/s)	**4.0**		**1.8**	
Eagle input tunnels	**East**	**West**	**East**	**West**
Air temperature in the tunnel (°C)	56	55	57	54
Busbar temperature, centre bar (°C)	76	86	73	86
Volumetric flowrate (m^3/s)	6.4	6.1	5.7	5.8

Mass flowrate (kg/s)	**6.5**	**6.2**	**5.8**	**5.9**

4.1.2 Cooling Fan Monitoring

Busbar cooling fans are critical equipment for busbar integrity. During the measurement of air flow rate in the long tunnel of Potline 7 south, it was discovered that one fan out of two in the east part of the tunnel was not blowing much air into the tunnel. Then, static pressure at the outlet of the fan was measured with a Pitot tube and it was only one half of the normal expected value. Next day, in another tunnel of the same potline, two fans were running but one of them was found to have only one tenth of the normal static pressure and did not give any airflow, and the temperature of the fan casing was 15 °C above the ambient temperature, being heated by the running motor and not cooled by the air throughput. These two cases indicated that static pressure of the fan, can be used to check whether a fan is working correctly or not. Following this, a full measurement campaign of fan static pressure was undertaken and several running fans were found defective, operating, but having unusually low static pressure. The faulty fans were immediately replaced and it was decided that in the future, static pressure of the fans will be measured every 6 months, to assure continuous busbar cooling. Other fan safety measures as part of fan maintenance program include automatic monitoring the motor running status, checking of the motor vibration, fan temperature, etc.

4.2 Busbar Temperature Measurements

Busbar temperatures are the most direct indicator of busbar cooling in the tunnels. Maximum busbar temperature is of most interest because it could damage the epoxy grout insulation below the busbars and the tunnel concrete if the temperature is too high. The maximum busbar temperature limit in the tunnels was agreed to be 150 °C, which is far below the 200 °C limit identified as a risk for epoxy grout long term stability. The limit of 150 °C was also used in the CFD simulations to optimize the tunnel cooling [2]. Intuitively and by CFD simulations, the highest temperature locations were identified and thermocouples (TC) installed. Altogether TC have been installed in 55 sites considered more prone to higher busbar temperature, and more installations are possible. The tunnel at each measurement site is covered with removable slabs for future maintenance of TC. At each site a commercial battery-operated device with 4 TC is installed with the 4 TC fixed on the busbars and in a few cases one of four also in the air above the busbars. The box is installed on the tunnel wall and has an antenna for the transmission of the signals to the plant SCADA system. Of course, considering the large area of the plant, a number of transmission stations had to be installed, too.

Figure 10 shows busbar temperatures at the outlet of the two Eagle input tunnels, at the same place where the cooling air flowrate was measured, given in Table 2. Measured busbar temperatures at the outlet of the east tunnel to Pot 121 in Potline 5A (PL 5A) are also shown. As discussed in the previous section, it is essential for Eagle input tunnels cooling that the large gratings at Pot 121 be partially closed to allow more air into Eagle input tunnels. The impact of closure on busbar temperatures was tested. Before 11 April the gratings had 4 openings of 75 mm x 1000 mm. From 12 April to 10 May, the gratings were completely open and since then, only 4 gaps of 50 mm (width) x 1000 mm (length) are open. During the opened gratings, the busbar temperatures at the outlet of Eagle input tunnels were 20 °C higher than when the PL 5A gratings were nearly completely closed. On the other hand, the large air flow through PL 5A tunnels decreased the busbar temperature in that location only by 10 °C. The optimized system now gives safe busbar temperatures, much below the acceptable limit, at both locations as seen in Figure 10.

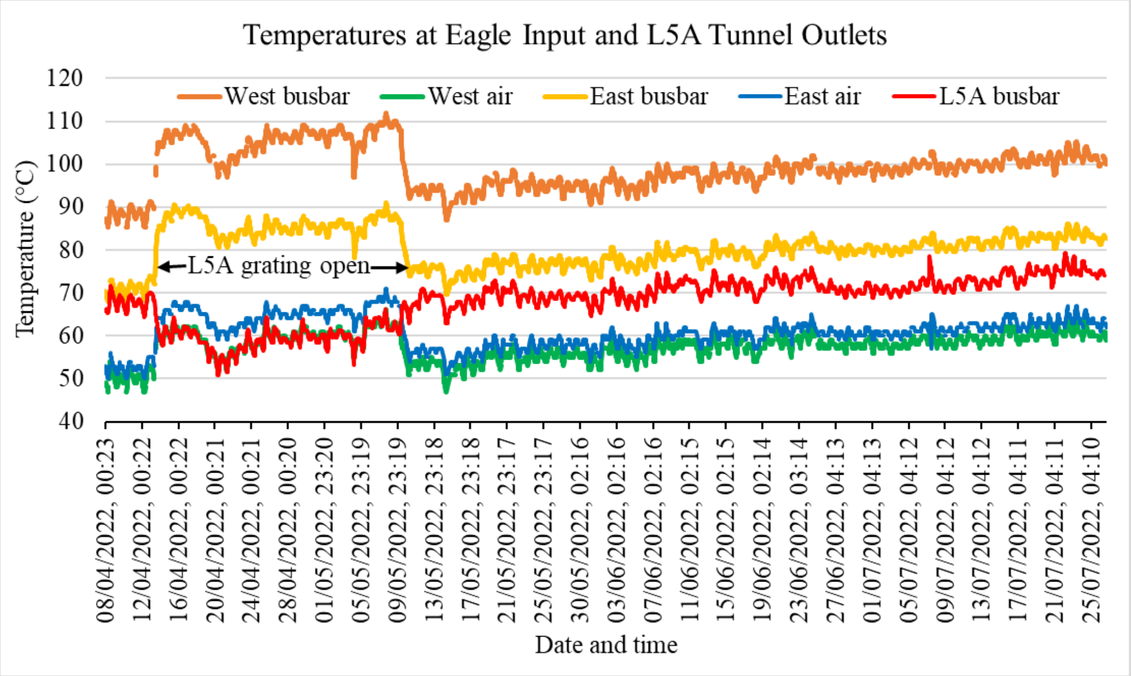

Figure 10. Continuous (hourly) monitoring of busbar temperatures in Eagle input circuit from 8 April 2022 to 26 July 2022. Temperature oscillations on the curves are daily variations.

4.3 Busbar Voltage Drop Measurements

As the ultimate safety measure for busbars in the whole length of the tunnels, the voltage drops are also measured and will be monitored automatically. Busbar voltage drop could increase because of higher temperature or because some busbars in a pack could be cut off. However, busbars in a pack are well protected against cut off of some of them because tie-bars every 3-5 m connect all the busbars together and any local cut-off of busbars increases the voltage drop only between two tie-bars, since the next tie-bar downstream immediately distributes the current to all busbars. A busbar temperature increase of 50 °C will increase the voltage drop by approximately 15 % through electrical resistivity increase. Such a temperature increase would be possible if the tunnel ventilation stops and in this could be detected by the voltage drop.

Many crossovers were equipped with voltage probes and a manual reading device in the potroom at the construction of the potlines. Some of these are still working and have been used to measure the voltage drops manually, periodically. The rest will be repaired or reinstalled. Testing is in progress to install automatic voltage drop monitoring.

5. Maintenance of the Busbar Cooling System

We have reviewed the time-based maintenance for the fans and adjusted the preventive maintenance frequency from 24 weeks to 12 weeks. The spare fan stock availability was reviewed in the warehouse and the stocks was increased, based on the recent experience and the advice of the planning team.

Condition based maintenance has been introduced by conducting fan vibration and temperature analysis on monthly basis. For the short term, the Condition Monitoring Group team will conduct the survey and for the long term, we are working on the feasibility of installing online fan vibration monitoring system.

To ensure continuous air flow of the fans, we have measured the static pressure at the base of all fans, using Pitot tube, which will be repeated every 6 months. For long term, we are going to do a trial by using an air flow sensor that will provide online readings for continuous monitoring.

For continuous monitoring of the fan status - (ON/OFF/TRIP), we have implemented the following:

1. SMS alert for each fan trip.
2. Provision of SCADA connection for potline shift in charge to control and monitor busbar cooling fan operations.
3. Busbar cooling fan full electrical current trend in the SCADA in order to track the historical records.
4. The audio announcement of busbar cooling fans by potline speakers.
5. Install beacon light near busbar cooling fan to alert potline operations.

6. Way Forward

As of the time of writing this paper, all crossover busbar tunnels in the Jebel Ali plant have been inspected. This included the removal of concrete slabs, inspection of tunnel and busbar condition and installing temperature monitoring sensors in recommended locations.

Most of the tunnels were in good condition, however, Potline 5 north and Potline 6 south tunnels showed signs of major deterioration and required immediate action. In Potline 5, civil work in B-room north tunnel has been completed, Work is ongoing in A-room tunnel and it is estimated to complete it by the end of November 2022. Potline 6 south tunnel repairs are starting in September 2022.

One interesting point of tunnels repair is that the potline operation will not be affected by this activity; this is achieved by installing a temporary bypass busbar and removing the existing underground busbar, so that civil work in the area can proceed safely.

The CFD study [2] showed that most Jebel Ali plant crossover busbars were operating within acceptable limits under current and future operating parameters. However, some crossover busbar tunnels required modifications listed below:

- Closing of some louver vents,
- Installing extra fans in some tunnels,
- Sealing (blocking the airflow) of tunnels with open busbar switch, where no current flows,
- Installation of monitoring devices,
- Modification to existing tunnels

Closing of louver vents: Based on the CFD model, it was recommended to completely seal louver vents in specific areas in Potline 7 and Potline 9 as they prevented air flow to certain parts of the busbar tunnels. This has been implemented.

Installing extra fans in some tunnels: The CFD study also recommended installing one extra standby fan in specific locations in Potline 5 Eagle, Potline 7 and Potline 9. In Potline 5, the civil work for the extra fan installation is ongoing. In Potline 7 south, long tunnel, the existing two fans on the east part and the west part of the tunnel will be operating continuously. One standby fan, recommended by CFD simulation [2], will be installed on the side of the two existing fans and connected in parallel directly to the busbar tunnel in order to avoid obstructing the traffic on the road behind the fans. Another CFD simulation will be done to confirm this, and then the fans will be installed. As for Potline 9, the recommendation is to relocate one fan from Section 7 north to the long tunnel. However, this can be done only after blocking the empty tunnel connecting section 7 to section 10.

Sealing (blocking the airflow) of tunnels with open busbar switch where no current flows: This is a major challenge as there are many existing tunnels with open switches, where currently no power is passing through the busbar in these tunnels. However, air is passing in them and this reduces air flow in active busbar tunnels. There are 7 such tunnels in Potline 9 as shown in Figure 13 of [2]. EGA Engineering Department is working on a solution for the blockage that can be easily installed and removed (dolomite sheet). One such blockage is already installed in the old crossover tunnel in Eagle Section of Potline 5 (Figure 6 in [2]). One will also be installed in Potline 7 south, between south crossover and the long tunnel (Figure 8 and 10 of [2]).

Installation of monitoring devices: The study also recommended installation of monitoring devices - temperature sensors on the busbars in the tunnels, in the recommended locations with the highest busbar temperature predicted by the CFD model. Currently, more than 50 % of the recommended locations are installed.

Modification to existing tunnels: Finally, the study recommended modification to some existing tunnels in Potline 6 and Potline 8 to optimize air flow for busbar cooling. In Potline 8, the south crossover tunnel is too high and wide, and much air passes in the empty tunnel beside the busbars. A mobile wall was recommended, based on CFD simulations to restrict the tunnel width and force the air around the busbars. This is still in design phase; a dolomite sheet wall is a good candidate for easy and safe installation.

7. Conclusions

Busbar linkages in Jebel Ali potlines are enclosed in tunnels below the roads and potline passageways. Cooling with fans is required to keep the busbar temperatures below safe limits. Large amperage increases generated much more heat in the tunnels, which eventually cut off busbars at input to Eagle demonstration section. This raised awareness of possible risks for busbar integrity in other potlines.

The Jebel Ali Busbar Integrity project was organized to eliminate any risks to the busbar integrity in the tunnels at present and future amperages. Practical investigation by opening the tunnels found that most of the busbars in the tunnels and the structure of the tunnels were safe. Some tunnels were damaged and were repaired or reconstructed. CFD modelling also showed that most short and simple crossovers and passageways were adequately cooled with the present setup of the cooling fans. In more complex tunnels, weaknesses were identified and improvements recommended. These have been or are being implemented. A large monitoring system for continuous fan operation, busbar temperatures and voltage drops has been set up. Preventive maintenance has been enhanced. This will guarantee long-term busbar safety and integrity at present and future amperages in all potlines.

Jebel Ali Busbar Integrity Project shows EGA’s capability to organize required human and material resources in response to any emergency or potential problem that may arise in the smelter.

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- Technology Development.
- Reduction Operations.
- Technical team.
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8. References

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