ALUMINIUM STEEL CONDUCTOR RAIL

FOR DC MASS TRANSPORT SYSTEMS

TYPE: ASS 3500
1 INtrodUctIoN

1.1 General

Aluminium steel conductor rails have been in operation for about 40 years. In the meantime, many changes have been made on the design and most of the mechanical problems with respect to mechanically joining of aluminium body and stainless steel strip have been remedied. However, new requirements with respect to easy installation, electric wear, EMI, and long-term joining of aluminium body and stainless steel strip but easy separation for recycling, usable and safe steel thickness, etc. remain fraught with problems and are not solved by one product yet.

1.2 Installation

Conductor rails are delivered in sections of up to 18 m. They are connected with each other by fishplates. Depending on the relative tolerances of the conductor rail to each other, a difference in position of the stainless steel strip of the joined rail sections may appear. Since the transition from one rail section to the next must be completely level, the stainless steel insert must be ground, which reduces the thickness and, therefore, the lifetime of the conductor rail. In addition, grinding needs to be realized over a longer distance to avoid that the transition becomes a ramp for the collector shoe. Particularly twisted rail ends of adjacent rails could make a preselection of rails necessary. Joining twisted rail ends often becomes very difficult and is time consuming. Heavy grinding of steel insert on both conductor rails always becomes necessary.

1.3 Electric Wear

Flat surfaces of steel insert without any wavy deviations on steel surface in the longitudinal direction is commonly agreed to be necessary for smooth running and improved electric contact of collector shoes.

The sparking between steel surface and collector shoe as a result of the lack of flatness and straightness of the stainless steel surface has the following adverse effect:

- Electro magnetic interference (EMI)
- Noise
- Electric wear of the steel strip

Considering that often 2/3 of the total wear is due to electric wear (electric sparking) and only 1/3 is due to mechanical abrasion, the smooth running of collector shoe could improve wear resistance considerably. Electric sparking between steel insert and collector shoe is substantially less on flat and non wavy steel surfaces.

1.4 Continuity of mechanical properties

Aluminium profiles are extruded from aluminium billets. In case the production of the conductor rail is continuous, billet after billet is loaded into the extruder. When new billet is loaded to the extruder, the process stops and a stop mark occurs. Stop marks are like a circular mark appearing around the profile at the exit of the extrusion die and indicates a stop position. Stop marks are consequently in front of the welding zone. In this zone, the material of a new billet follows the material of the old billet. In the welding zone of the two billets the material properties of the extrusion profile become worse, especially material strength is lower and the material properties cannot be guaranteed in that particular rail section.

1.5 Durable mechanical interlocking

Based on the type of joining the stainless steel strip to the aluminium body, the strength of the mechanical interlocking may be impaired while the thickness of stainless steel strip reduces. This effect may only be experienced after a long operation period. Since the thermal expansion of steel and aluminium is very different, it is of importance that the mechanical interlocking does not depend on the wear of the stainless steel strip.

1.6 Summary

According to our experience and statements made by railway personnel, the following requirements have to be improved:
- Overall reduced dimensional tolerances
- Non-wavy steel surface
- Consistent material properties
- Durable mechanical interlocking
2 TECHNICAL DATA

2.1 Dimensions

Fig. 2.1.1 Rail Cross Section

2.2 Nominal Data of the Conductor Rail

The conductor rail ASS 3500 features the following electrical properties:

- total cross section: 4,230 mm²
- total weight: 14.2 kg/m
- effective useable thickness of steel insert: 6 mm
- electric resistance per m: 9.16 µΩ at 20 °C (*)
- electric resistance per m: 11.54 µΩ at 85 °C (*)
- temperature coefficient: 0.004 K⁻¹
- transition resistance: 20-300 µΩ (point to point)
- 1 s - short circuit: 277 kA
- 3 s - short circuit: 160 kA
- nominal current: please see table below (*)

(*) dependent on local conditions and specification

Fig. 2.1.2 3D view of the Rail
2.3 Nominal Technical Data of the Material

Technical data for:

<table>
<thead>
<tr>
<th>Property</th>
<th>aluminium</th>
<th>stainless steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific electric conductivity, min (20 °C)</td>
<td>MS/m</td>
<td>30</td>
</tr>
<tr>
<td>Specific electric conductivity, typical (20 °C)</td>
<td>MS/m</td>
<td>31-32</td>
</tr>
<tr>
<td>Temperature coefficient of resistance</td>
<td>K⁻¹</td>
<td>0.004</td>
</tr>
<tr>
<td>Yield point</td>
<td>MPa</td>
<td>170</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>MPa</td>
<td>215</td>
</tr>
<tr>
<td>Hardness</td>
<td>HB</td>
<td>85</td>
</tr>
<tr>
<td>Modulus of elasticity</td>
<td>GPa</td>
<td>69</td>
</tr>
<tr>
<td>Modulus of transverse elasticity</td>
<td>GPa</td>
<td>27</td>
</tr>
<tr>
<td>Specific weight</td>
<td>g/cm³</td>
<td>2.7</td>
</tr>
<tr>
<td>Specific heat</td>
<td>J/(g·K)</td>
<td>0.92</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/(m·K)</td>
<td>197</td>
</tr>
<tr>
<td>Thermal coefficient of expansion</td>
<td>10⁶ K⁻¹</td>
<td>24</td>
</tr>
</tbody>
</table>

(thermal expansion of the composite conductor rail is approximately 19 x 10⁶ K⁻¹)
3.1 General

Considering the needs as mentioned in Chapter 1 above, it was necessary to develop a new type of conductor rail, which incorporates already approved manufacturing processes. The aluminium steel conductor rail is made out of two main parts:
- the extruded aluminium rail (aluminium extrusion profile)
- a pre-manufactured stainless steel insert

In the following the main parts, the manufacturing process and logical advantages are described in detail.

3.2 Aluminium Rail

3.2.1 Material

The aluminium rail is extruded of special selected aluminium billets within the specified standard aluminium alloy AW6060 or similar. This alloy guarantees state-of-the-art material properties, i.e. high mechanical strength and optimum electric conductivity.

3.2.2 Extrusion die

The aluminium conductor rail is extruded as a single profile. Within each extrusion process there are only minor deviations in absolute dimensions at all, while relative tolerances from conductor rail to conductor rail are going to a minimum.

3.2.3 Stop marks

The aluminium conductor rail is extruded billet on billet, but each section of welding zone (stop mark) is cut out as shown below. None of the aluminium conductor rails shows a stop mark or welding zone of different billets. This guarantees uniform, high mechanical properties across the entire length.

3.2.4 Water quenching

The rail is extruded and water quenched in a vertical position to avoid any torsion to the left or right side. Any deformation due to different thermal shock impact (water cooling) is therefore minimized or even avoided.

3.2.5 Inspection Certificate

The quality of the material is controlled by chemical analyses of the aluminium billets and mechanical properties of each heat treatment charge are certificated according to Inspection Certificate (EN10204-3.1).

3.2.6 Summary

The production method has the following advantages:
- single extruded profile
- same conductor rail height
- water quenching with profile in a vertical position
- no twist of (adjacent) conductor rail ends
- no grinding of steel insert
- no stop marks / no welding zone within conductor rails
- high material strength all across the entire length of the conductor rail
- selected aluminium billets, outstanding material properties
- small symmetry grooves in the fishplate pockets and middle of aluminium base
- small grooves help to find the drilling position, i.e. drilling holes for joining rails on site

3.3 Stainless Steel Insert

3.3.1 Stainless Steel Material

The stainless steel insert is pre-manufactured from the material X6Cr17. This stainless steel quality has been tried and tested for over 40 years under the specific conditions of heavy underground and high-speed railways. Its high chromium content of 17 % guarantees highest stainless steel corrosive resistance. The special stainless steel material offers highest mechanical wear resistance and best electric wear resistance even under difficult conditions of sparking and arcing. The use of high alloy 17 % chrome steel prevents electrical corrosion between aluminium profile and stainless steel insert even in the presence of an electrolyte, wetting by water and frost.

3.3.2 Pre-manufacturing

The stainless steel inserts are manufactured in appropriate lengths and then mechanically adjusted and assembled onto the aluminium
rails as one straight long bar. Prior to this, stainless steel strip is bent to take on a C-shape, which gives high rigidity and stability. Any waves or other longitudinal deformations are eliminated. Stainless steel strip is flat on total length and offers smooth steel surface in longitudinal as well as in transversal direction for optimum collector shoe gliding and electric contact under operation.

### 3.3.3 Steel Thickness

The steel thickness determines service life of the conductor rail and is therefore most important in terms of total cost. Therefore, conductor rail ASS 5100 offers 6 mm wear thickness. Due to the method of assembly of the stainless steel insert to the aluminium rail, the whole thickness of 6 mm can be used for wear.

### 3.4 Assembly of Steel Insert and Aluminium Rail

The stainless steel insert and aluminium rail are interlocked mechanically under ambient temperature conditions. After assembly the conductor rail is only shortened/cut to the required length. The stainless steel insert is fixed to top of the aluminium rail by pressing aluminium continuously on both sides of the aluminium conductor rail into holes within the stainless steel insert. Interlocking is below wear thickness of stainless steel and therefore attachment is not affected by wear, as clamped steel insert may be.

The aluminium interlocking in longitudinal direction of the rail also ensures that the different thermal expansion of steel and aluminium (bi-metal effect) is irrelevant. While the clamping force of clamped steel strip dramatically decreases with the wear thickness, sliding between aluminium and steel may not occur due to the patented aluminium interlocking technique.

The punching is below wear thickness of steel to provide original mechanical interlocking during whole lifetime and also under conditions of heavy wear. No part of steel will come loose even if completely worn. These conditions makes the conductor rail more secure under operation and tolerates long intervals between the routine inspections.

No minimum steel thickness must be measured and monitored for safe operation and providing evidence in case of legal investigations. The conductor rail has to be removed after abrasion occurs if the abrasion has reached the aluminium.

The punching also provides high electric transition contact between aluminium rail and stainless steel insert which is not affected by wear as well either. Punching provides high contact pressure and, therefore, high electrical performance. Nevertheless, steel insert is pre-stressed on top of the aluminium rail, this also improves the electrical contact. Manufacturing technology provides smooth and safe overall surface of the conductor rail. There are no sharp cutting edges or aluminium splices that may injure installation staff.

After expiry of the life of the rail the remnants of the steel strip have to be separated from the aluminium for reasons of recycling and environmental protection. The aluminium interlocking can be removed, and aluminium and steel insert can be 100% separated, offering customer highest revenue of recycled material.

This method of manufacturing has the following advantages:

- permanent material interlocking at both sides of aluminium conductor rail
- durable interlocking during whole lifetime
- interlocking not affected by wear or remaining steel thickness
- no part of steel will come loose even if it is completely worn
- 100% aluminium and steel separation possible for reasons of recycling
- no clamping of steel insert
- no longitudinal slippage between aluminium and steel insert possible
- interlocking prevents from damage caused by thermal expansion of steel and aluminium
- high electric contact by interlocking through high press contact
4 NOMINAL PROPERTIES OF CONDUCTOR RAIL

4.1 Electrical Properties

4.1.1 Electrical Resistance

Electrical resistance R per meter of Aluminium Steel Conductor Rail can be calculated according to formula

\[ R = \frac{1}{1 + \frac{1}{R_{\text{Steel}}} + \frac{1}{R_{\text{Alu}}}} \times \frac{1}{A_{\text{Steel}}} \times A_{\text{Alu}} \]

with \( A = \) cross section, \( \sigma = \) specific conductivity.

According to \( R_{\text{Steel}} = \frac{A_{\text{Alu}}}{A_{\text{Steel}}} \times \frac{\sigma_{\text{Alu}}}{\sigma_{\text{Steel}}} \times R_{\text{Alu}} \), electrical resistance of stainless steel insert is much higher compared to electrical resistance of the aluminium rail (\( R_{\text{Steel}} = 150 \times R_{\text{Alu}} \)) and, thus, does not have to be considered for the calculation of the overall resistance. Furthermore, the steel insert is subject to abrasive wear and steel resistance increases with time and wear.

4.1.2 Electrical Resistance at operation conditions

During operation the conductor rail heats up to a certain operation temperature \( u \). At high temperature however, the conductor rail resistance is higher according to temperature coefficient \( \alpha \) according to \( R_u = R_0 (1 + \alpha (u - 20\,^\circ K)) \); \( \alpha = 0.004 \, K^{-1} \),

with \( R_0 = \frac{1}{\sigma_{20^\circ C}} \times \frac{1}{A_{\text{Alu}}} \).

Electric resistance of conductor rail can be calculated according to the above mentioned formula, but aluminium conductivity depends on heat treatment of the aluminium alloy. Conductivity varies in between 30 MS/m (guaranteed minimum) and 32 MS/m for very good conductivity. However, the average value is exceeding 31 MS/m according to long-term experience.

4.1.3 Transition Resistance of Aluminium Steel Conductor Rail

To estimate the transition resistance between aluminium rail and stainless steel insert, a point-to-point measurement as shown in fig. 4.1.3.1 was carried out.

According to diagram below, the transition resistance depends on the distance of measuring points, i.e. contact #2 at position 2a on left side or position 2b at steel centre line as shown besides. At outermost position near the aluminium interlocking transition resistance further decreases. Aluminium interlocking provides high electric conductivity due to high pressure contact to the stainless steel insert.

![Diagram of aluminium-steel transition resistance (interface resistance)](image)

At rail ends transition resistance doubles because the electric current flow is restricted to one “half” (only one aluminium side). But this is a physical phenomenon and does not indicate any deterioration of conductor rail quality.
Measured transition resistance also depends on the arrangement of electrodes. Data on relevant datasheets can only be compared, if transition resistance is measured by same measuring electrodes, since there is no uniform standard for the measuring devices. It is important that stainless steel thickness dominates the transition resistance because of its poor conductivity compared to aluminium conductivity. Conductor rails with 6 mm steel insert show higher transition resistance than conductor rails with 5 mm.

4.1.4 Total Transition Resistance

Transition resistance between aluminium rail and stainless steel insert is of lower importance than expected. The measurements as given in the above sheet are only a single point to point transition resistance. Therefore, these value have less significance to the overall electric quality of conductor rail as explained below:

Each collector shoe contacts the rail on many different contact points or else a part of the surface at the same time. This means that many transition resistances are electrically connected parallel to each others and total transition resistance becomes much less.

If the collector shoe runs on a flat surface, the total transition resistance between conductor rail and collector shoe is much better as operating on wavy steel surfaces because the total contact surface area is larger.

In addition, any contamination on stainless steel surface significantly affects total transition resistance between stainless steel surface and collector shoe, which is much higher than the transition resistance between aluminium and stainless steel.

Considering a total transition resistance between aluminium and stainless steel insert of $R_T = 10$ Microohm which can be regarded high under normal operation conditions, electric loss at $I = 1,000$ A is $P_T (I) = R_T \cdot I^2 = 10$ Watt and can be neglected while considering the total power losses of a 500 m conductor rail. For example: $I = 1,000$ A is $P_E (I) = 9.2 \mu \Omega/m \cdot 500$ m $\cdot I^2 = 4,600$ Watt. The power loss of a 500 m conductor rail is about 4.6 kW and much higher compared to any transition resistant power loss.

4.1.5 Short Circuit Resistance

In the event of short circuits the rail resistant losses lead to increasing conductor rail temperature. The maximum permitted rail temperature is 200 °C, therefore, the temperature rise is mainly defined by aluminium rail heat capacity. Air cooling or heat radiation need not to be considered for such short periods.

Normally, a short circuit is cleared within less than 100 ms. Therefore, short circuits do not adversely effect aluminium steel rails in view of thermal stress. It warms up very little, even during short circuits lasting extended periods of time.

4.1.6 Nominal Current

The nominal current of the conductor rail is based on the ambient temperature and the acceptable operating temperature of the conductor rail. The table and diagram under Chapter 2 shows the values. For an ambient temperature of 25 °C and a permitted operating temperature of 70 °C, the nominal current is 3,500 Amps.

4.2 Mechanical Properties

4.2.1 Bending Aluminium Steel Conductor Rail

Aluminium Steel Conductor Rail of 15 - 18 m length is very elastic and pre-bending does not have to be carried out.

For radii $R \geq 100$ m the aluminium steel conductor rail is installed elastically into conductor rail supports. If radius $R$ is less than 100 m, pre-bending may be recommended. However, it will be done at site and not done in the factory.

4.2.2 Thermal Expansion of Aluminium Steel Conductor Rail

Thermal expansion of aluminium and stainless steel is different. $\alpha_{\text{steel}} = 12.0 \times 10^{-6}$ K$^{-1}$, $\alpha_{\text{alu}} = 23.8 \times 10^{-6}$ K$^{-1}$. The overall thermal expansion of the conductor rail = $\alpha_{\text{alu-steel rail}} = 19 \times 10^{-6}$ K$^{-1}$. 
Below, a summary of the benefits of the conductor rail ASS 3500 is shown:

**single extrusion profile**
- lower tolerance
- no grinding, higher lifetime
- easier installation

**quenching profile in vertical position**
- lower torsion
- no grinding, higher lifetime
- easier installation

**no welding zone / no stop mark**
- constant mechanical properties
- higher short circuit capacity
- higher mechanical stress

**pre-manufactured straight steel inserts**
- no bending of steel insert during extrusion
- no wavy steel surface
- less wear, longer product lifetime
- silent operation
- less strain on collector shoe
- less EMI

**firm steel aluminium interlocking, no clamp**
- steel attachment does not depend on clamping force
- interlocking not affected by wear
- no slippage of aluminium and steel possible
- no minimum steel thickness, no need to be supervised