New long stator winding (LSW) cable with Aero-Z conductor for high speed up with short round-trip time

Harald Buethe, Francois Daugny, Dr. Holger Fastabend,
Dr. Dirk Steinbrink, Peter Zamzow
Nexans Deutschland Industries GmbH & Co KG
Bonnenbroicher Str. 2 – 14, D-41238 Moenchengladbach, Germany
+49(2166)27-2723, harald.buethe@nexans.com, www.nexans.com

Keywords

AERO-Z®, Long Stator Winding (LSW), LSW cable, propulsion, Transrapid

Abstract

This article describes how Nexans succeeded to merge the highly sophistcated AERO-Z® conductor for overhead power lines and the Transrapid cable, the heart of the Transrapid long stator. A diameter equivalent AERO-Z® conductor will have 3 – 5.5 % higher ampacity and the smooth surface, close to a solide conductor, enables a better adjustment and control of the triple layer insulation extrusion.
The electrical performance tested according IEC 60502-2 proved that the AERO-Z® conductor is fully compatible to the standard conductor deployed for the Transrapid Shanghai LSW and the bending and crimping test results show, that the AERO-Z® conductor requires significant less bending force and exhibits an improved shaping performance.
This pinpoints that the unique combination of the AERO-Z® conductor and the LSW cable will open new horizonts for the adaption of the Transrapid propulsion to the different requirements of future Transrapid projects.

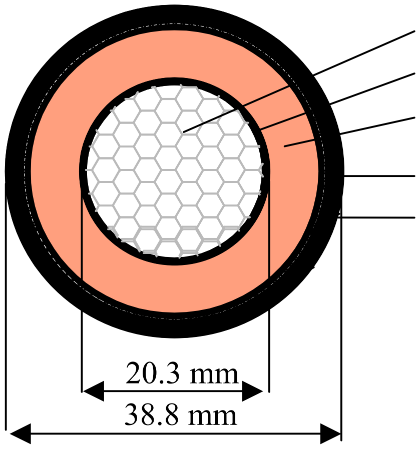
1 Introduction

The propulsion of the Transrapid high speed MAGLEV technology is based on the principle of a synchronous linear motor that is used for both, propulsion and braking. The long stator of the linear motor stretches along under both sides of the guideway and comprises epoxy resin coated stator packs, stainless steel grounding sleeves, grounding wires and the so called long stator motor winding (LSW). The LSW is the only component being installed on site as it extends over the entire length of a motor section having a typically length of about 1 km. The installation is carried out by automated laying vehicles on the guideway, performing an in-line bending, crimping and pressing of the phase windings in three consecutive steps. Up to six laying vehicles were utilized at the same time for the installation of the 1000 km of LSW cable used for the two tracks of the 30 km long Transrapid Shanghai demonstration line from Pudong international airport to downtown Long Yang Road station.

Picture 1 : Installed LSW on the track

2 The Long Stator Winding Cable

The Transrapid Shanghai propulsion is energized by a pulsed power supply of up to 20 kV, with a maximum current rating of 700 A, frequencies ranging from 50 Hz to 250 Hz and the maximum power on time of a motor section is up to two seconds. The LSW of the Transrapid Shanghai line uses a special 20 kV medium voltage (MV) rubber cable with a special designed 300 mm² aluminium conductor of superior electrical and mechanical performance. Picture 2 shows the basic design of the LSW cable, materials and dimensions of the LSW cable, which Nexans supplied for the Transrapid Shanghai airport link.

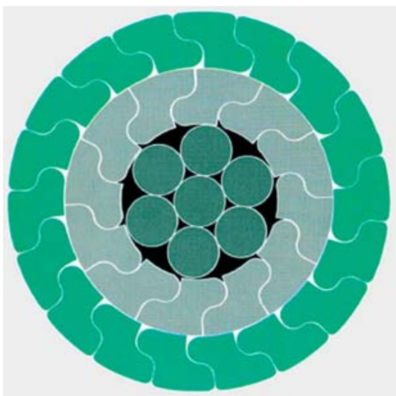


Picture 2 : Design of the LSW cable

The basic LSW cable design is transferred from the test track in Lathen. The increase of the voltage level from 15 kV to 20 kV for the Shanghai application required an adjustment of the insulation thickness, that Nexans obtained by gradually improving the compacting ratio of the aluminium conductor, as the increase of the outer diameter was impossible due to the fixed size of the stator grooves. The present conductor has a reduced diameter of 20.3 mm instead of the original 20.9 mm, thus creating the neccessary space for the increase of the insulation thickness.
This design modification for the Shanghai project is very likely to reflect the needs of specific adjustements for further project on the one hand, but it shows on the other hand the strong limitations imposed by the geometry of the approved linear motor system of the Transrapid's propulsion.

3 The AERO-Z® Conductor

AERO-Z® conductors are highly sophisticated conductors for high-voltage overhead power lines up to 380 kV, developed by a Belgian subsidiary of Nexans. The AERO-Z® conductor was developped several years ago to obtain longer spans and higher transit ampactity, thus giving the economical and ecological equal attractive possibility to upgrading existing lines instead of being forced to systematically building new lines. They are recently well established with several Belgium and French power supply companies.



Picture 3 : Design of AERO-Z®

3.1 The AERO-Z® Design

The name AERO-Z® conductor reflects the genuine part of the design, tew Z like profiled wires used for the outer layer of the conductors. Depending on the overall size, one or two layers are applied giving a virtually very smooth surface with small helical grooves on the outside.
The layers with Z shaped wires are regarded fully-locked, i.e. they

form a firmly fitted circular belt around the core.

3.2 AERO-Z® Characteristics

Cigré [1] reported the below in compressed form listed highlights that had been established by the Van Kaman Institute in Brussels:

- **Increased transit ampacity** from 11 – 16 %
- **Reduced drag coefficient** up to 40%
- **Reduced corrosion** due to the fully-locked layers with Z wires
- **Undestrandability**, i.e. a broken wire of the outer layer remains in place
- **Self-damping,** i.e. AERO-Z® conductors dampen typical oscillation 2 to 3 times faster
- The **galloping** amplitude is significantly reduced
- Improved **snow and frost accretion**

3.3 AERO-Z® and the Transrapid LSW cable

As the compacting ratio of the standard conductor is brought to a limit where further improvements are not reasonable to obtain, there seamed no way to improve the ampacity of the LSW cable without sacreficing the obtained voltage level. The introdution of the AERO-Z® conductor with an evident higher compacting ratio seems to open the two possibilities,

- bigger cross section for the same diameter to increase ampacity, or
- simliar cross section at a smaller diameter to open a range for furtehr adjustments of the cable make-up.

The mechanical advantages of the of the AERO-Z® conductor experienced with overhead power lines seem not too relevant for a MV cable application, but in particular the significant stability against dynamic mechanical stress is likely to predict an interesting mechanical apprearance of the appropriate LSW cable.

4 The LSW cable trial with AERO-Z® Conductor

4.1 The AERO-Z® conductor design for the 20 kV LSW cable

Nexans decided to designed and produced an AERO-Z® conductor in their Dour/Elouge plant in Belgium, to match the the outer diameter of the standard LSW conductor, i.e. maintaining the design of the present LSW cable. Table 1 lists the characteristic of the two different conductor types, highlighting a higher specific weight of the AERO-Z® conductor. This documents the increased compacting ratio and thus a 3 % higher transit ampacity than the regular conductor. It is under consideration to use compacting for first layer of circular wires which will further increase the specific weight even up to 815 kg/km respectively 5.5 % transit ampacity gain.

Attributes of the aluminium conductor	Standard Conductor	AERO-Z® Conductor
diameter of wires	2.54 mm	2.9 mm
number of wires	60	37
number of layers	1 + 4	1 + 3
Outer diameter	(20.3 – 0.1) mm	(20.3 ± 0.1) mm
Specific weight	770 kg/km	795 kg/km

Table 1

The AERO-Z® LWS trial cable was produced in the Monchengladbach plant of Nexans, where the 1000 km of Transrapid LSW cables for the Shanghai airpot link have been previously produced.

Identical production parameters were applied to assure a high comparatibility with the regular production.

4.2 Geometry of the LSW cable

Pictures 4 and 5 give a cross sectional comparison of the two different LSW cable types. The regular conductor appears more compacted than the AERO-Z® conductor which is visually missleading. Due to the rubber on the outside, it was not possible to completely polish the surface suffuciently.

Picture 4 : Standard conductor

Picture 5 : AERO-Z® conductor

As can be seen too, the smooth surface of the the AERO-Z® conductor shows an improved circularity of the inner conduction layer.
A reference samle of the regular production was selected and the geometry of both samples were measured. Table 2 gives a comparison of the results documenting that the reference sample is sufficient close to the AERO-Z® trial cable, to assure comparability of the tests results.

Dimension	Specified value	Standard Conductor	AERO-Z® Conductor
Conductor diameter	max. 20.9 mm	20.4 mm	20.4 mm
Thickness of the insulation	min. 5.0 mm	5.61 mm	5.54 mm
Diameter of the core	-	33.16 mm	33.18 mm
Thickness of the sheath	min. 2.1 mm	2.31 mm	2.35 mm
Outer diameter	(38.8 ± 0.2) mm	38.9 mm	39.0 mm

Table 2 : Geometry of the LSW cable samples

4.3 Electrical Tests

The AERO-Z® trial cable underwent and passed the electrical tests according IEC 60502-2, confirming a full electrical compatibility with the standard conductor. The previously predicted ampacity improvement of 3% is thereby confirmed by the DC resistance test results.

Electrical Characteristic	Specified value	Standard Conductor	AERO-Z® Conductor
DC resistance @ 20 °C	≤ 0.1 Ω/km	0.0978 Ω/km	0.0952 Ω/km
Mutual capacitance @ 50 Hz	≤ 0.42 µF/km	0.357 µF/km	0.379 µF/km
Voltage test @ 30 kV/50 Hz	5 min	passed	passed
Partial discharge @ 24 kV/50 Hz	≤ 20 pC	3.4 pC	1.2 pC
Dissipation factor @ 20°C, 24 kV/50 Hz	≤ 0.003	0.003	0.003

Table 3 : Electrical characteristics acc. IEC 60502-2

4.4 Mechanical Properties

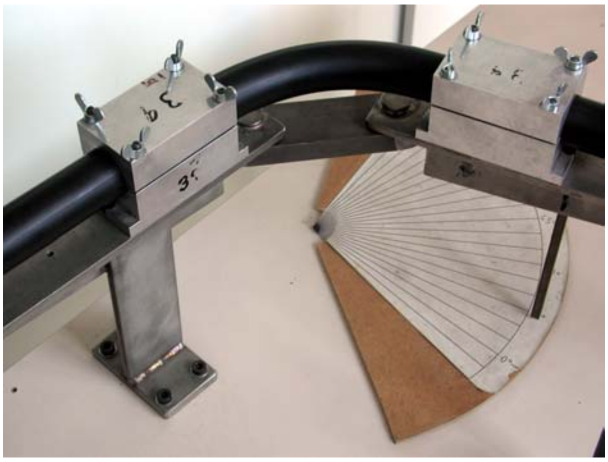
The mechanical tests of the program proved to be the most exiting part. The mechanical appearance of the LSW cable is widely influenced by the conductor and due to the specific laying conditions, the mechanical requirements are very specific and beyond the scope of a any MV power cable specification. These tests are designed to assure a reliable automated processing with the laying vehicles used on site. The applied test setups comply with the LSW product specification [2] for the Transrapid Shanghai project.

4.4.1 Bending property (manual)

A cable sample is mounted in the brackets of the test setup shown in picture 6. One end is uniformly bent by 90° and then released. During the complete test, the bending force is recorded and the backspring angle of the cable can be read from a below fixed scale.

	Bending force	Backspring angle
Standard Conductor	70 N	14 °
AERO-Z® Conductor	45 N	13 °
Difference	- 36 %	- 8 %

Table 4 : Bending properties



Picture 6 : Test of manual bending property

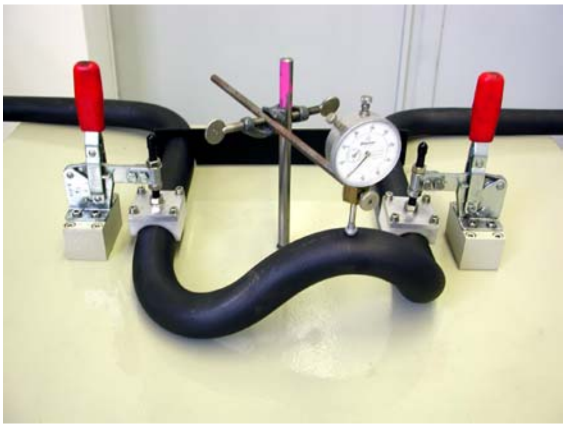
Table 4 displays a significantly reduced bending force of the AERO-Z® conductor, already signalized from feedbacks during the production, saying that this LSW cable “feels more flexible”. The difference in backsping angle is not regarded significant at it is in the range of the reading accurcy. An affirmation is due to further tests on other LSW cables with AERO-Z® conductors.

4.4.2 Automated bending / Form stability

The test is performed on a stationary bending and crimping machine built according the Transrapid Shanghai project specification. The machine produces one-sided meander of the three different LSW phase patterns. Nexans introduced this regular sample test for the Transrapid Shanghai project to have a factory based preliminary examination of the automated bending/crimping behaviour and form stability of the LSW cable prior to the shipment to Shanghai. The phase 2 pattern turned out to be the most critical patter due to the 80 mm step crimping in the middle section of the u-bow (picture 7).

Immediatelly after the bending/crimping, the meander is placed on a plane-table to determine the effective crimping heigth and to monitor the variantion in heigth after 30’ and 10h.
The crimping of phase 2 applies plastic deformation to the conductor, buffered by the rubber corset of the LSW cable, which represents as many as 73% of the total volume. As this effect is quite obviously affected by the crimping speed, we we decided to also variy the crimping speed in addition to the routine test procedure, to enable an assessment of the behaviour at the higher speeds used with recent units.

Picture 7 : Bending/crimping unit (phase 2)



Picture 8 : Plan-table for test of the form stability

Crimping speed	Standard Conductor	AERO-Z® Conductor	Delta
[mm/s]	[mm]	[mm]	[mm]
4.4	95.95	103.05	7.10
5.8	95.30	102.35	7.05
8.3	92.30	100.20	7.90
10.7	91.40	98.55	7.15

Table 4 : Crimping heigth

As can be seen from table 4, the LSW cable with AERO-Z® conductor shows a signifcantly improved crimping heigth for identical processing parameter, which is obviously maintained throughout the different crimping speeds applied. The form stability in heigth measured after 30’ and 10 h is below 0.01mm for both samples as usual.
This is in fact the most surprising result of the mechanical tests as it indicates that the LSW cable with an AERO-Z® conductor is likely to even have a significatly improved mechanical performance.

5 Summary

The above outlined test results show that Nexans made a very fortunate decision, to introduce the AERO-Z® conductor to the LSW cabel design. In addition to the expected improvement of the transit ampacity, the AERO-Z® cable shows unexpected superior mechanical properties, making it an ideal candidate to replace the approved standard conductor design.
In particular the mechanical properties will be subject of further studies in addition to the presently not conducted system long term homologation tests proving the electrical and mechanical stability after simulated climate tests, electrical operation [3], thermal treatment [3] and oscillating mechanical strain, to obtain the full offical product approval and to establish this exiting new cable design as an approved solution for the Transrapid LSW application.

6 Acknowledgments

We thank the Nexans Dour/Elouge plant in Belgium and in particular Daniel Guery for their techical support and contribution to the AERO-Z® LSW trial cable.

References

1. P. Couneson, J. Lamsoul, D. Deplantque, Th. Chapelle, M. Havaux, D. Guery, X. Delree, *Improving the performance of existing high-voltage overhead lines by using compact phase and ground conductors,* Conseil International des Grands Réseaux Électriques (**cigré**), France 1998

2. ThyssenKrupp Transrapid GmbH, *TBT/9364/11/03*, Germany 2003

3. Harald Buethe, Dr. Sarah Le-Dren, Dr. Dirk Steinbrink, *Special MV cable for long stator winding application Transrapid Shanghai*, Jicable'03 proceedings, France 2003