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PRESS FILE

Copper in the transport systems of the future

THE EXAMPLE OF THE HIGH-SPEED TRAIN

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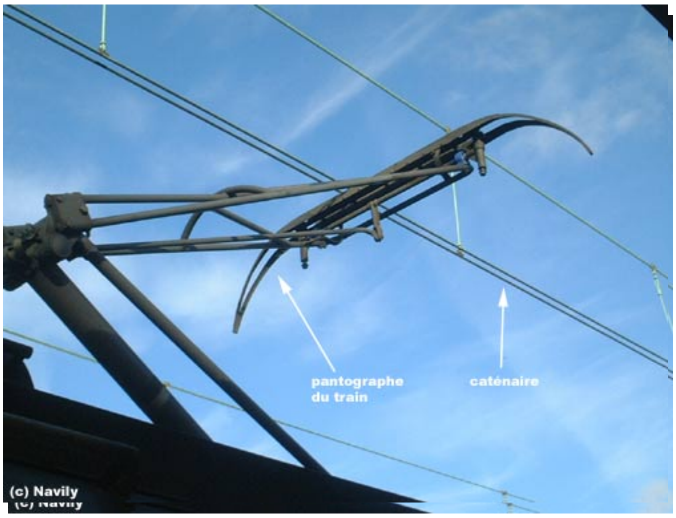
I. THE "CATENARY BARRIER": COPPER RESOLVES A TECHNOLOGICAL CHALLENGE

A catenary system consists of two conductor wires: the first, the catenary wire, is a copper-tin wire which supports the second, the contact wire, which is made from pure copper or a copper alloy and supplies electrical current to the train pantograph. The contact wire is suspended from the catenary wire so that it is horizontally parallel to the track. The catenary system is supported by pylons and is arranged such that it weaves from side to side of the track centre line so that the contact wire does not wear a groove into the train pantograph.

10 tonnes of copper are used for every kilometre of dual track catenary system.



[picture: train's pantograph, catenary]

‣ What is the "catenary barrier"?

Like the sound barrier for air travel, high-speed trains are constrained by a physical speed limit known as the "catenary barrier". This limit is a real challenge for engineers seeking to set new rail speed records.

3 questions for Roland Lehoucq

3 questions for Roland Lehoucq, Doctor of Physics and Researcher attached to the Astrophysics Department of the French CEA (Saclay Atomic Energy Commission)

Author of *Les pouvoirs de Superman*, *Mais où est donc le Temple du Soleil*, *Faire de la science avec Star Wars*, *Les lois du Monde*; his next book is entitled *SF: la science mène l'enquête.*

1) Is there a physical limit to the speed that a train travelling on rails can reach?

"Several parameters limit the speed of a train. The most unexpected of these concerns the delicate problem of capturing the current. Because of the train's movement, the catenary is subject to vertical vibratory motion. In order for the catenary to deliver the electrical current, the train's speed must not exceed the speed of the waves that displace the catenary. The speed of propagation of vibration waves would act as a speed limit, a "catenary barrier", similar to the sound barrier. Usually, the speed of propagation of these mechanical waves is close to 500 kph, which sets a maximum speed limit for high-speed trains at some 470 kph. In practice, the TGV may not exceed a speed of 70% of the speed of wave propagation throughout the length of the catenary."

2) What happens when approaching the "catenary barrier"?

"The magnitude of displacement increases with speed and becomes greater as the train approaches the speed of wave propagation. The catenary's upward displacement can exceed 30 - 35cm in places. This phenomenon erodes energy capture, which could result in disconnection of the traction units, damage to the equipment or even bring the train to a complete halt."

3) How can this type of risk be avoided?

"Breaking a rail speed record means pushing back the catenary barrier, which means increasing the speed of the waves that are propagated at that point. The simplest solution would be to increase the catenary's mechanical tension, taking care not to break it, naturally."

The "catenary barrier" was extended by using catenaries made from copper alloys under high mechanical tension.

Copper plays a dual role here:
1. It improves electrical **conductivity in the catenary**, which is a vital function for delivering power to the train;
2. Alloyed with cadmium or magnesium, **it improves the catenary's tensile strength** thereby enabling greater mechanical tension. The greater the tension of the catenary, the less the magnitude of displacement it is subjected to. This allows us to extend the "catenary barrier" and to set new speed records.

Catenaries in Europe

Source: interview with Michael Köhler, from Diehl Metall, a specialist in the research and development of catenaries.*

- The greater the tensile strength of the material used for the catenary, the greater the possible tension. This in turn opens ups the possibility for trains to set new rail speed records. Because of the improved mechanical tensile strength, catenaries made from copper-magnesium and copper-cadmium alloys are gradually supplanting other types of catenary. In France, the RFF and SNCF use a copper-cadmium alloy.

- In Germany, the Deutsche Bahn pioneered the use of copper-magnesium alloy. Spain turned to this new alloy for the 580 km of wires between Madrid and Seville installed in 1990-91 and, more recently, for the wires between Madrid and Lerida. In Holland in 2004-2005, the Nuremberg-Ingoldstadt link was also constructed using copper-magnesium.

- The UK, on the other hand, uses a copper-silver alloy which, although having a lower tensile strength than copper-cadmium and/or copper-magnesium, has better electrical conductivity.

* Diehl Metall is a German manufacturer of Semifinished products.

Speed records in France:

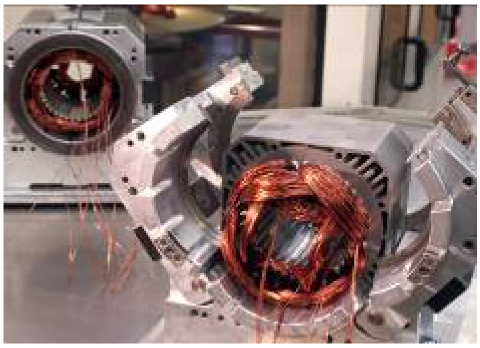
In 1990, the tension of the catenary was increased to 3,000 daN (more than 30 times that of a piano string). With this development, the TGV Atlantique trainset number 325 reached a record speed of 515.3 kph.

In 2007, with the tension of the catenary increased to 4,000 daN in places, the speed of mechanical wave propagation was once again increased. On 3 April at 13:13, the V150 trainset recorded a speed of 574.8 kph, setting a new rail speed record.

II. COPPER: THE KEY TO HIGH PERFORMANCE

COPPER'S IDENTITY CARD:

- **Symbol**: Cu
- **Code name**: Red metal
- **Density**: 8.92 kg/dm^3
- **Electrical conductivity**: 59.6×10^6 S./m
- **Ordinary state**: Solid
- **Presence in the earth's crust**: 55g per tonne
- **Presence in living organisms**: 1 to 10mg per kg



Remarkable properties:

- **Conductivity**
  Of all the common metals, copper is the best conductor of electricity. It proves to be very effective in improving energy efficiency.

- **Suitability for the formation of alloys**
  As most elements are soluble in copper, there is immense scope for copper alloys. Copper alloys are widely used. The most widely known alloys are brass (copper-zinc) and bronze (copper-tin).

- **Corrosion resistance**
  Copper and its alloys are highly resistant to outside forces (water, the atmosphere and chemical products). This property guarantees the quality and durability of the products directly exposed to the external environment, such as roofing, pipes and catenaries.

- **Recyclability**
  Copper is 100% recyclable indefinitely, without any loss in performance. Recycled copper is 99.9% pure, like primary copper, and can be used as is.

Where is copper used in trains?

- **In the catenaries**, because it is the best electrical conductor, highly resistant to corrosion, can take high mechanical tension and is easily alloyed with other elements, such as magnesium.

- **In power wires and cables**, because it ensures reliable and optimum energy distribution.

- **In electric motors and transformers,** because its excellent conductivity helps to deliver the best electrical efficiency.

- **In on-board electronic systems**, because copper forms the core of chips and circuit boards.

What are the major industrial sectors that use copper?

The use of refined copper in Europe is broken down as follows[1]:

- **Electricity and energy** (including wires and cables in construction): **58%**;
- **Construction** (including architecture and pipes): **26%**;
- Engineering (machines, tooling, common objects, coins): 10%
- Transport: 5%;
- Other: 1%.

[1] Source: *International Wrought Copper Council* (IWCC).

III. FOCUS: VELARO, THE FASTEST HIGH-SPEED TRAIN TO DATE

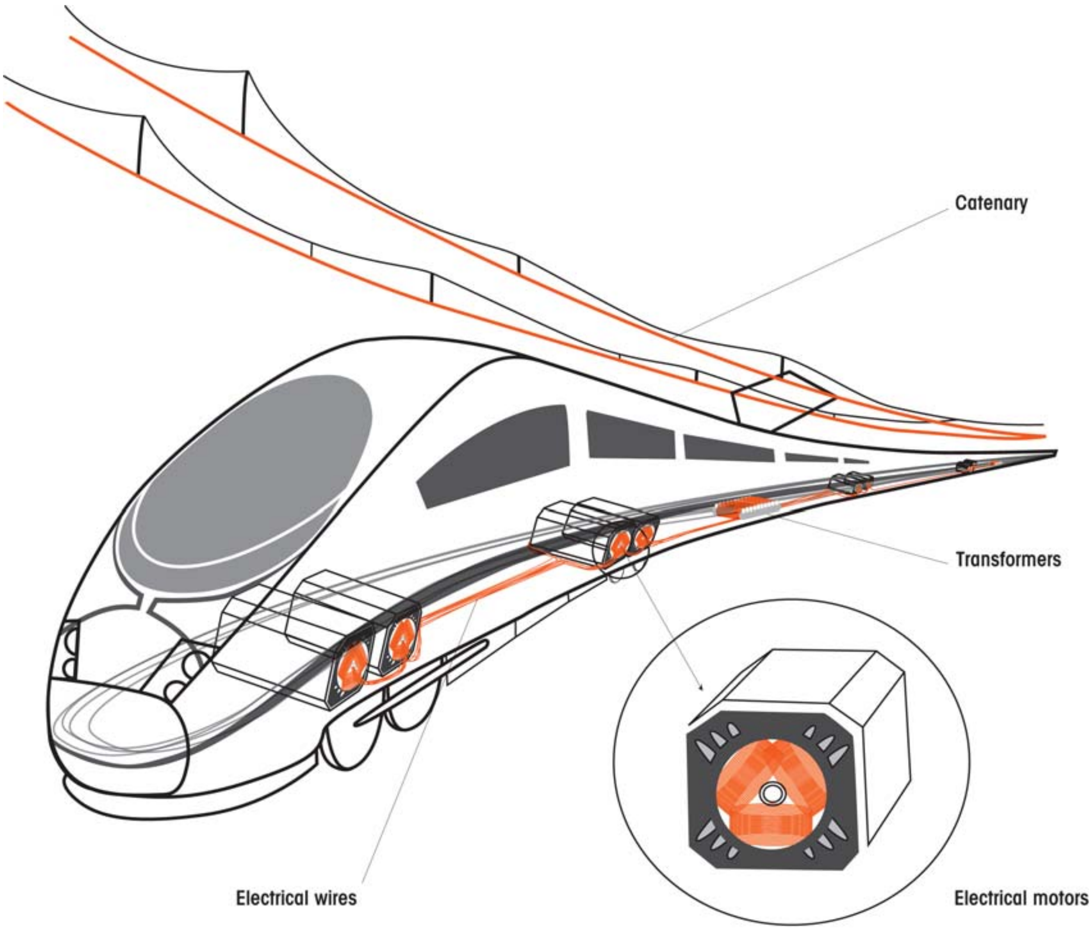
Siemens's ICE 3 (Inter-City Express 3, the "German TGV") is the fastest high-speed train to date in the world (travelling at speeds of up to 330-350 kph during commercial services). Four lines equipped with this new-generation train set are currently being opened:

- the LGV Madrid-Barcelona line
- the LGV Beijing-Tianjin line
- the LGV Moscow-St Petersburg and Moscow-Novgorod lines

The Spanish Railway Operator, RENFE, ordered the "Velaro" ICE from Siemens to serve the new Madrid-Barcelona line from December 2007. It will cover the 650 km between the two cities in a mere 2 1/2 hours - twice as fast as its predecessors.

The amount of copper used in conventional electric trains is 1 to 2 tonnes with 2 to 3 tonnes used in TGVs. **ICE 3 / *Velaro* however requires 3 to 4 tonnes of copper**, in particular because of its traction system based on the impressive number of motors: no fewer than 16. In addition, each kilometre of catenary system contains 2.5 tonnes of copper on average, which is a total **of 10 tonnes per km**. A catenary consists of an upper and lower wire and runs above the track on both sides.

"*Taking its inspiration from ICE 3, Velaro is based on a platform concept featuring interoperability that can be exported throughout the world"*, said Friedrich Moninger, innovation strategist at Siemens Transportation Systems (STS). Velaro can travel at 350 kph using 25,000-V copper catenary on rails with a standard track gauge of 1,435mm. It can seamlessly cross borders and change sector voltage (according to the standards in the different countries) either while the train is running or stationary.



Above: copper in the Spanish Velaro *high-speed train.*

▸ Motor trainsets: a new generation of high-speed trains

ICE 3 / Velaro is a motor trainset consisting of four identical and independent traction units. The motors are fitted with copper cage rotors, capable of producing 500 kW and reaching a maximum speed of 6,000 rpm. Half of the axles have their own drive system.

There are major advantages attached to these technical specifications:

- If a traction unit fails, it can be disabled without affecting the remaining units. This means the train can reach its destination in complete safety with 75% of its maximum traction and braking power;
- With its acceleration power the train can climb gradients of up to 4% (twice the capability of a conventional passenger train).

The traction engines, transformers, cable network and all the technical modules are located underneath the passenger space over the full length of the train. This accommodation of the technical modules underneath the train translates into a fully passenger-dedicated space throughout, delivering 20% more space compared to a conventional train of the same length and offering unrivalled passenger comfort.

Opposite:
ICE 3/Velaro on the assembly line

▸ The secret of Velaro's speed: *high tech* copper-magnesium catenaries

The catenaries installed over ICE 3's and Velaro's route are made from a copper-magnesium alloy. The alloy's mechanical tensile strength makes it possible to achieve speeds of up to 400 kph (compared to 160 kph for conventional catenaries). The service life of this type of wire is 4 times longer than that of former types.
Siemens's research and development teams are already working on developing new catenaries using copper-chrome-zirconium alloys, which promise to provide even better tensile strength and service life.

Opposite:
Electronics are omnipresent in Velaro's cockpit.

Below: ICE 3 on the move

ANNEXE 1: HISTORY OF THE TRAIN

From antiquity: invention of wagons guided along grooves

There is agreement among historians that the Romans used a system of transportation similar to our modern railroads to facilitate convoys. This system consisted of horse-drawn wagons (or drawn by cattle) the wheels of which were guided along in grooves. In fact, some Roman roads had two grooves, with a fixed distance between them, that were very similar to our modern railways.

1550: the first proven use of wagons on rails

Horse-drawn wagons running on wooden rails appeared in France in the middle of the 16th century and then spread throughout Europe. The oldest proof of the existence of wagons running on wheels (not motorised) dates back to 1550: traces were found in engravings from the Alsace region showing small wagons in the Leberthal mines.
In the beginning of the 18th century iron wheels and rails began to appear (in England in particular). These systems were known as tramways.

1804: the first steam locomotive operated on rails

The invention of the steam engine at the end of the 18th century was revolutionary and steam power was soon in use for different applications, including transport. At the dawn of the 19th century, the English engineer, Richard Trevithick, designed a train pulled by a steam locomotive. The train ran for the first time on 21 February 1804 in Wales.
After a series of improvements, the railway system spread, developed first in England during the first half of the 19th century and quickly gaining popularity in Europe and then America.

Copper, with its excellent thermal conductivity, was used for steam engine fireboxes for the efficient transfer of heat to the boiler.

1900: appearance of electrical traction

From around 1900, power and sufficiently compact electric engines led to the development of electrified railways, a technology still in use today. This method of traction requires a catenary line over the tracks to supply the train with electricity through a pantograph.

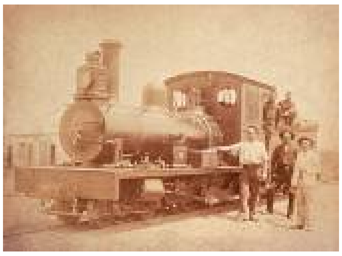
1959: construction of the *Shinkansen* in Japan

Construction of the Japanese Shinkansen began at the end of the 1950s to link Tokyo to Osaka using a high-speed line. It opened on 1 October 1964. Today, Japan is working on a new generation of high-speed magnetic levitation transport or Maglev trains. The first of these projects is intended to cover the 400 km between Tokyo and Osaka in 1 hour.

1981: launch of the high-speed Paris-Lyons train link

The first French high-speed line was the LGV Sud-Est (LN1) (South-east line). The decision to build the line goes back to 1974 but it did not start operation until September 1981. The LGV Sud-Est considerably reduces the journey time between Paris and Lyons (2 hours), using a more direct rail line that reduces the distance between the two French cities from 512 to 426 km and TGV technology delivering average speeds of 270 kph for commercial service.

ANNEXE 2: RAILWAYS FROM PAST TO FUTURE



Steam train

- Speed: 8 kph for the 1 train, to 203 kph for the historical record (a steam-powered locomotive pulling 6 wagons). Average speed for commercial service: 50 kph
- Technology: boiler and steam engine
- Power: 300 to 1,000 steam horsepower
- **Quantity of copper: 1-2 tonnes / engine**
- Example: Cévennes train

Electric train

- Speed: outside the historical record (331 kph), the average speed of electrical trains operating commercially is 80 to 200 kph
- Technology: electrical power via catenary and pantograph or central rail
- Power: 2.3 MW (3,000 bhp)
- **Quantity of copper: 1-2 tonnes / train set + 10 t / km**
- Example: regional express trains

Front wheel drive high-speed trains

- Speed: from 210 kph for the 1st Japanese Shinkansen (1964), to 320 kph for today's TGV Est. Average speed in commercial service: 270 km/h. World speed record: 574.8 kph (TGV)
- Technology: power supplied by catenary; one or more electric locomotives
- Power: 9.3 MW (12,500 bhp)
- **Quantity of copper: 2 - 3 tonne / train set + 10 t / km**
- Examples: Eurostar, Lyria, TGV, ICE 1 & 2...

New distributed drive train

- Speed in commercial service: 330 - 350 kph
- Technology: engine and distribution traction throughout the length of the train underneath the train sets (20% more passenger space)
- Power: up to 8.8 MW (11,800 bhp)
- **Quantity of copper: 3 - 4 tonnes / train set +10 t / km**
- Examples: Velaro, ICE 3

ANNEXE 3: MAP OF TODAY'S HIGH-SPEED TRAINS

The German ICE (Inter-City Express) was developed by a consortium led by Siemens. In use since 1991, it serves several rail links within Germany and to neighbouring countries. The 3rd generation of ICE travels at over 300 kph. The Spanish incarnation of ICE 3 is known as "Velaro" and is set to travel between Madrid and Barcelona reaching peak speeds of 350 kph.

The TGV, built by Alstom and operated by the French Railway Operation, the SNCF, holds the latest rail speed record (not to be confused with magnetic levitation trains like the Japanese Maglev). In service, the TGV can travel at speeds in excess of 320 kph.

Eurostar links London and Paris in 2 hours and 35 minutes and London and Brussels in 2 hours and 20 minutes. It also has services serving Lille, Calais and Ashford. England opened a new 74 km section of track in September 2003; a second (34 km, 22 km of which is in a tunnel) is due to open on November 14th 2007. The terminus for this new section will be London's St Pancras station. This development will shorten the time between London and the French capital to 2 hours and 15 minutes.

The Thalys connects Paris to Brussels (some 300 km) in 1 hours and 22 minutes. This LGV is being extended to Amsterdam and Cologne. Thalys will share these lines with the Eurostar trainsets linking Brussels and Paris to London, the TGV trainsets providing the connection between Paris and the north of France, as well as the ICE trainsets linking Germany to Brussels.

In Japan the Maglev (Magnetic Levitation train) holds the world train speed record since 2 December 2003, with a speed of 581 kph. This Japanese magnetic levitation train uses a line and not a rail like conventional trains. For now, the only currently operating commercial application of this technology is between Shanghai and Pudong airport.

The Japanese Shinkansen, built by Kawasaki, Hitachi and Nippon Sharyo, was launched during the 1964 Olympic Games and links Tokyo to Osaka. The first Shinkansen travels at 300 kph and is operated in Japan and Taiwan. A prototype of the new Shinkansen - "Fastech 360Z" - is expected to see the light of day in 2008. It is currently being tested. The aim of this new Shinkansen is to travel at 360 kph during commercial services.

The Swedish X2000 has been operated by the Swedish State Railways (Statens Järnvägar) since 1995. This tilting train runs at a maximum speed of 210 kph.

The Zefiro, built by Bombardier, is due for launch in Canada in the next few years, where it will provide the fastest commercial service on that continent (200 to 350 kph).

ANNEXE 4: THE EUROPEAN COPPER INSTITUTE

The European Copper Institute (ECI) is a European joint venture between the main copper producers worldwide (represented by the International Copper Association) and the European copper industry. Its mission is to promote the advantages of copper for modern society throughout Europe through its head office in Brussels and its European network of 11 copper information centres.

The ECI is active in four key areas in Europe:

1) ECI's electricity and energy programme

The aim of the ECI's electricity and energy programme is to promote the rational use of energy within a framework of sustainable development. It has three priorities:

- **Energy efficiency**: by increasing its research, itaims to increase awareness and provide information by participating in Community action programmes, such as "Motor Challenge", which encourages industry to use systems driven by more efficient electrical motors.
- **Quality of electric power**: ECI is the founder of a Community professional training programme (LEONARDO Power Quality Initiative) aimed at improving the quality of electrical power and reducing electrical problems. Implemented in 12 countries, the programme involves over 100 organisations, including some famous universities, companies and professional organisations. The programme aims to achieve savings of EUR 10 billion per year by reducing electrical disturbances.
- **Electrical safety and comfort**: ECI set up a European working group to improve electrical safety in the home, bringing together the main players in the sector: FEEDS (Forum for Enhanced Electrical Domestic Safety).

2) ECI's automotive and construction programme

Both the construction and automotive sectors are key areas for the ECI. Its promotional work in these areas are based around three pillars:

- **Architecture and pipe systems**: with the aim of promoting the aesthetic qualities of copper, its durability and its natural anti-bacterial properties, widely recognised water, heating and gas distribution systems.
- **The role of copper in solar power**: with the aim of making the most of copper's remarkable heat conductivity as a key factor in the exploitation of solar power.
- **The advantages of copper in the automotive industry**: with the aim of promoting the role of copper in improving the safety and comfort of modern cars and in the development of tomorrow's electric cars.

3) ECI's environmental programme

The European Copper Institute's environmental programme is primarily aimed at understanding the potential effects of copper on the ground and water. The results are used in regulatory debates at both EU and national level. All research is carried out with the aid of renowned scientists.

4) ECI's health programme

The Copper Institute's health programme primarily aims to understand copper's role in the health sector. Its results are used to improve health and to contribute to regulatory debates.

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