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New 30 m Flexible Hybrid Energy Transfer Line with Liquid Hydrogen and Superconducting MgB2 Cable – Development and Test Results

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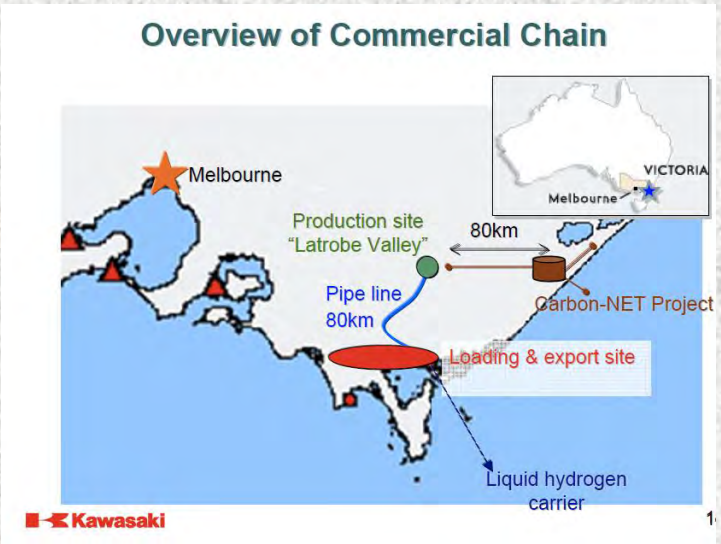
OUTLINE

- *THE IDEA*
- *FIRST RESULTS IN RUSSIAN HYBRID ENERGY TRANSFER SYSTEM PROGRAM (2011) – JUST REMINDER*
- *SECOND STAGE (2013) – NEW 30 M MgB_2 CABLE, NEW FLEXIBLE 30 M CRYOGENIC LINE AND CURRENT LEADS*
- *CURRENT TEST*
- *ELECTRICAL TEST*
- *CRYOGENIC TEST*
- *CONCLUSIONS*

THE MAJOR IDEA OF THE PROJECT

- ***SUGGESTION:*** ***SOMEBODY ALREADY HAS HYDROGEN TRANSFER LINE FOR ANY PURPOSES***
- ***(SAY LIKE JAPANESE – AUSTRALIAN PROJECT OF HYDROGEN PRODUCTION AND DELIVERY AS LIQUID VIA 80 KM PIPELINE)***
- 

ICEC25 & ICMC2014,7-11 July 2014 @ University of Twente , Enschede, The Netherlands

Study on Introduction of CO2 Free Energy to Japan with Liquid Hydrogen

Shoji Kamiya, Motohiko Nishimura, Eiichi Harada , et al.

Kawasaki Heavy Industries, Ltd.

- ***SO, HAVING LH_2 LINE WITH "GRATIS' COLD, WHY NOT TO PUT THERE SUPERCONDUCTING CABLE AND TO DELIVER MORE ENERGY?***
- ***THIS IS EXACTLY WHAT WE WOULD LIKE TO DO!***

NOT TO COOL A CABLE BY HYDROGEN, BUT TO INCREASE ENERGY DELIVERY BY AN EXTRA SUPERCONDUCTING CABLE!
IT IS: THE HYBRID ENERGY TRANSFER LINE

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – FIRST STAGE 2011

10 m cryostat and cryogenic line without high voltage opportunity

Total cooling time ~380 s.

Estimated heat losses were below 10±2 W/m,

Current lead losses at 2600 A~300 W.

Temperature variations form 20 K to 26 K,

pressures from 0.12 to 0.5 MPa

LH_2 flow from 10 to 250 g/s.

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – FIRST STAGE - CONCLUSIONS

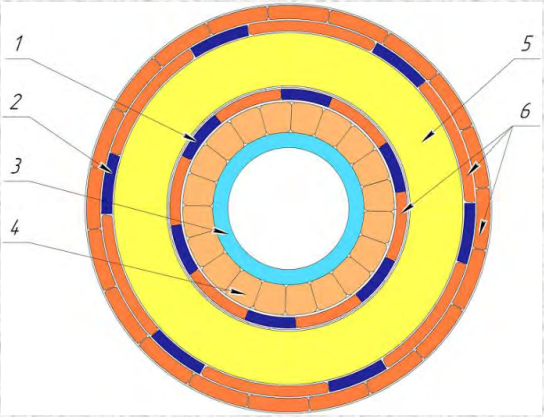
- With LH_2 flow **250 g/s** – the delivering power is **~31 MW**.
- Superconducting cable at **2.5 кА** and potentiality of 20 kV – is able to deliver extra **50 MW**, or **80 MW** in total with only 5 tapes
- It is easy to add five or ten tapes more and we can increase electrical power to 100 – 150 MW, total power to 130 - 180 MW.
- **The energy transfer line tested is able to deliver energy flow more than 100 MW**

The conception of hybrid energy transport system has been proved experimentally

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – SECOND STAGE - PLANS

- Longer, ≥30 m high voltage cable
- Longer ≥ 30 m flexible cryogenic line;
- To try different thermal insulation methods of hydrogen cryostats;
- Current test with higher currents;
- High voltage test;
- More hydrodynamic and superconducting data at liquid hydrogen

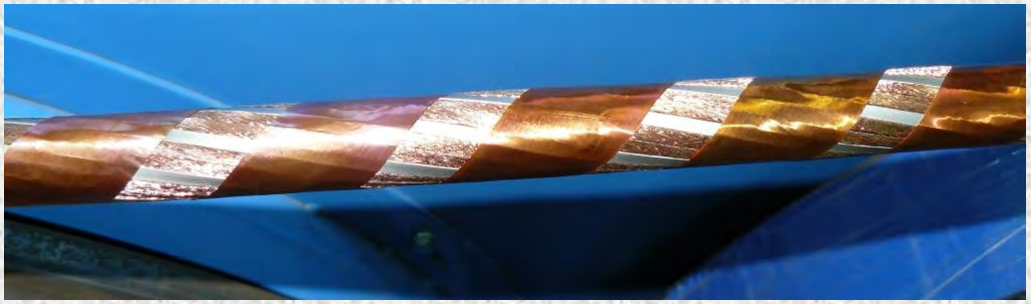
RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – second stage – MgB2 cable



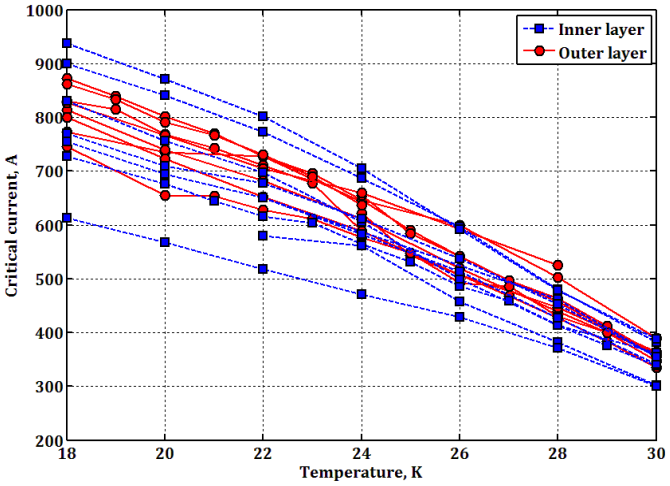
1- Inner superconducting layer made of 6 MgB_2 tapes with O.D. ~13.8 mm; 2 - Outer superconducting layer made of 6 MgB_2 tapes with O.D. ~22.8 mm; 3 – supporting SS spiral, I.D. ~8 mm; 4 – copper strands bunch; 5 – high voltage insulation made of crepe cable paper; 6 – separators made of flattened copper strands bunches. Cable total outer diameter ~24.5 mm.

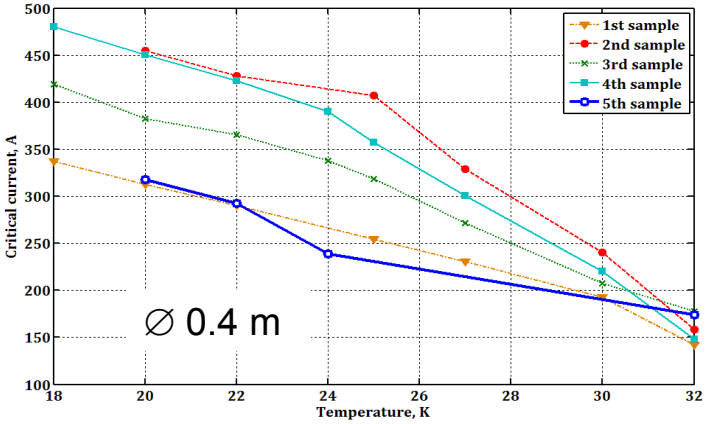
- 30 m length
- Six MgB_2 tapes (expecting critical current at 20 K >3000 A)
- High voltage insulation 3.7 mm made of crepe cable paper
- 35 mm^2 protection copper bunch of wires
- Completely industrial production

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – second stage – MgB2 cable – production and checking after production



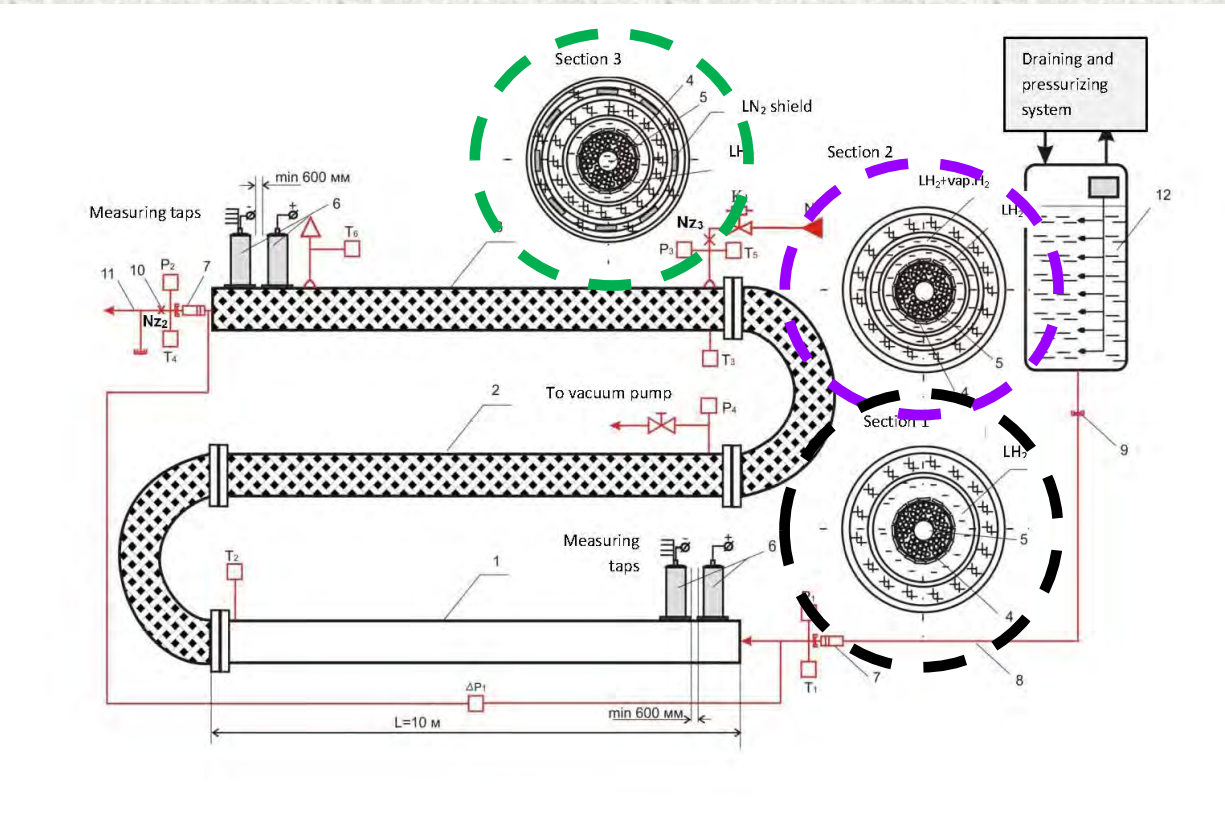
After twisting Ic(T) is OK





Bending on less then 1 m may destroy wires

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – SECOND STAGE –NEW CRYOSTAT



Three main sections ~10 m each.

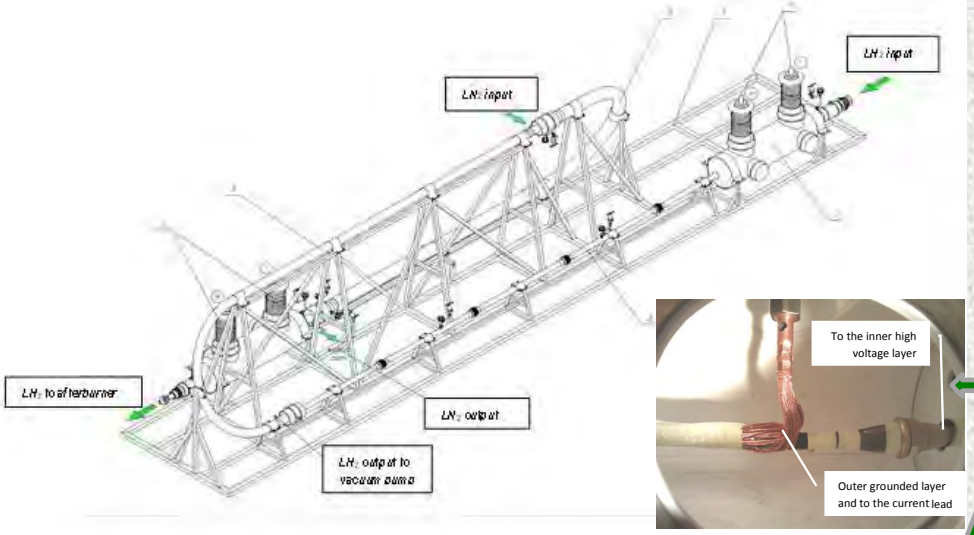
The first section is an insulated cryostat "pipe-in-pipe" with VSI - **those cryostat as in 2011**

The second section is a flexible cryostat made of corrugated tubes with reinforcement.

Active evaporating cryostatting system. Part of LH_2 flow – is being directed to the auxiliary channel with pumping out to lower pressure and, therefore, to lower temperature

The third section is also a flexible cryostat with **liquid nitrogen shield** as insulation.

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – SECOND STAGE –NEW CRYOGENIC LINE



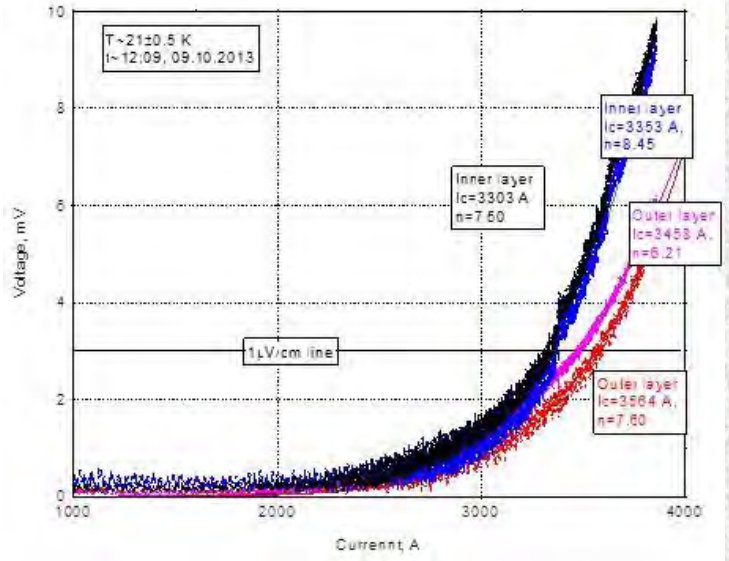
- Flexible transfer line are mounted on 11 meters load frame made of welded steel profiles
- It provides a rigid attachment of all elements as well as it allows the handling and transportation by ordinary tracks

High voltage current leads and special splicing with the cable

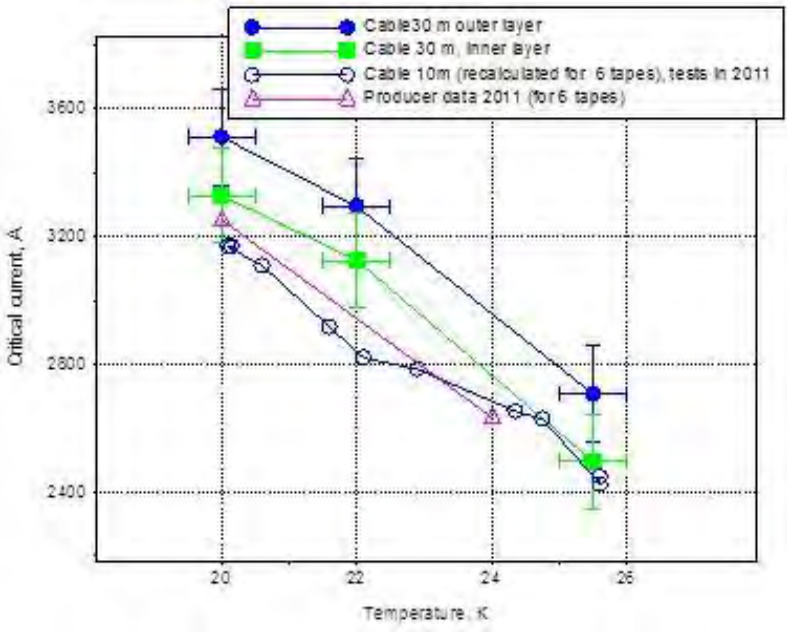
RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – TEST FACILITY

The special facility intended for testing oxygen–hydrogen liquid propellant rocket engines with liquid hydrogen production plant of the KB “Khimavtomatika”, Voronezh city.

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – SECOND STAGE – CURRENT TEST



V-I characteristics measured via current leads with subtraction of bias voltage
Temperatures 20-26 K
Pressure 0.25-0.5 Mpa
LH_2 flow – 70-450 g/s



At 20 K I_c >3200 A - 3500 A
No heating of LH_2 observed close to I_c.
Operation currents ~2400 - 3000 A recommended
Comparison with 2011 demonstrates that MgB_2 wires became better.

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – SECOND STAGE – HIGH VOLTAGE TEST

Cryostat body and outer layer – grounded
Inner layer connected to the high voltage source
DC 10 kV steps with stops ~15 min at each level
Maximum - at 50 kV.
Leakage currents less than 10 μA
Allowed operation voltage - 25 kV

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – SECOND STAGE – CRYOGENIC TEST - AEC

Parameter	Regime1	Regime 2	Regime 3
P1, bar	3.88	5	3.88
DP1, bar	0.5	1.75	1.86
P3, bar	2.32	2.6	2.5
P4, bar	1.9	1.14	0.85
T1, K (at the input to the line)	25.1	22.35	20.4
T2, K (at the input to the section 2)	25.6	22.8	21.1
T3, K (at the input to the section 3)	24.8	21.78	21.1
T4, K (at the output from the line)	25.3	22.14	22.3
T5, K	107.9	110.6	139
T6, K	81.6	75	94
G, g/s (H_2 flow in the main channel)	110	160	230
Gкр,g/s H_2 flow in the auxiliary channel)	0.8	1.7	1
GN_2,g/s (N_2 flow in the auxiliary channel)	77	83	81

Max LH_2 flow was up to 450 g/s.

LH_2 flow in auxiliary channel ~1-2% of main channel

Active evaporating cryostatting system drastically reduces heat inflow and permit to increase a unit length of a cryostat

RUSSIAN PROGRAM FOR HYBRID ENERGY TRANSFER LINES – SECOND STAGE – CONCLUSION

- The tests of the 30 m cable prototype were successful: **currents 2400-3200 A, voltage up to 25 kV allowed**
- The **sufficient advantages of active evaporating cryostatting system** have been demonstrated with extra flow ~1% of general flow only
- First ever made 50 kV high voltage tests demonstrated **good dielectric properties**
- Chemical power is up to **60 MW**, electrical power is up **75 MW**, or **~135 MW in total**.
- Power flow density **~$1 \cdot 10^6$ W/cm^2** with relatively small current. **Close to those for oil or gas transferring lines**

GENERAL CONCLUSIONS

- High power (tenths of GW) with high power flow density energy transfer systems for long distance (~1000km) is a challenge for XXI century energetics
- The use of the MgB_2 superconductor significantly reduces the cost of a system and use of LH_2 as a cryogen and energy source may increase power flow.
- Feasibility of hybrid energy transfer systems has been proved by experiments
  - High voltage test performed
  - Active evaporating cryostatting system demonstrated sufficient reduction of heat to liquid hydrogen channel with opportunity to increase unit length of cryostats
- Power density flow achieved was ~ $1 \cdot 10^6$ W/cm^2 and could be easily increased

High power hybrid energy transfer systems with liquid hydrogen and superconducting MgB_2cable became reality !

Thank you for your attention !

And do not afraid of hydrogen – it is not so explosive as you think! ☺

Fuel Gas	"Lower Explosive or Flammable Limit" (LEL/LFL) (%)
Hydrogen	4
Propane	2.1
Kerosene Jet A-1	0.7
Diesel fuel	0.6
Fuel Oil No.1	0.7
Gasoline	1.4