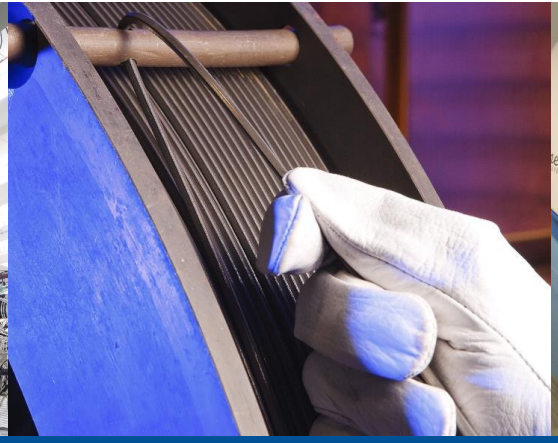
IEEE CSC & ESAS SUPERCONDUCTIVITY NEWS FORUM (global edition), December 2021.
Invited presentation 1S-p02 was given at the virtual Cryogenics and Superconductivity Society of Japan, 101st 2021 Virtual Spring Meeting, 19-21 May 2021.

ASG SUPERCONDUCTORS


A HISTORICAL EPISODE ON DEVELOPMENT OF MgB_2 MATERIALS AND CURRENT STATUS OF ITS APPLICATION

GIOVANNI GRASSO, ASG SUPERCONDUCTORS

20 years anniversary of MgB_2 superconductor

MY SECOND DECADE MEMORIAL SPEECH ON MgB_2..

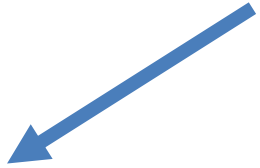
MgB_2 ten years after:
present state and perspectives for superconducting wires

Giovanni Grasso

Columbus Superconductors

Trondheim, Norway, June 13th, 2011

TEN YEARS AGO I GAVE THIS SPEECH..



HOW FAR ARE WE TODAY FROM OUR HOPES?

ASG SUPERCONDUCTORS

ASG TODAY: A DYNAMIC COMPANY

Columbus Superconductors

LEADER IN PROVIDING THE CUTTING-EDGE TECHNOLOGY OF MgB_2 SUPERCONDUCTING WIRES FOR APPLICATION IN ENERGY, MEDICAL, INDUSTRIAL

ASG Superconductors

MARKET LEADER IN LARGE SUPERCONDUCTING SYSTEM DESIGN, MANUFACTURING AND SUPPLY FOR A VARIETY OF APPLICATIONS AND CUSTOMERS GLOBALLY

PARAmed MEDICAL SYSTEMS

INVENTORS OF THE MR-OPEN: THE ONLY MRI PRODUCT WITH A "TOTALLY OPEN-SKY" MAGNET SOLUTION, THAT DEFEATS CLAUSTROPHOBIA AND ALLOWS MULTI-POSITION IMAGING

Almost FOUR DECADES OF SUPERCONDUCTIVITY INDUSTRY now merged in a single company

ASG SUPERCONDUCTORS

ASG is now producing SUPERCONDUCTING WIRES, COMPONENTS AND FULL SYSTEMS

ASG SUPERCONDUCTORS columbus mgb2 unit

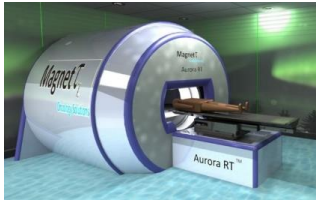
ASG SUPERCONDUCTORS magnets & systems unit

ASG SUPERCONDUCTORS paramed mri unit

ASG: LOCATED IN THE NORTH-WEST OF ITALY

ASG SUPERCONDUCTORS

ASG BUSINESS STRATEGY: MgB_2 MAIN FOCUS NOW

TECHNOLOGIES	CONVENTIONAL	INNOVATIVE	
 ASG SUPERCONDUCTORS columbus mgb2 unit			From MgB_2 WIRES to POWERING CABLES
 ASG SUPERCONDUCTORS magnets & systems unit			REFRIGERATION-COOLED POWER DEVICES for the electricity grid
 ASG SUPERCONDUCTORS paramed mri unit			ROTATING MRI applied to cancer therapy

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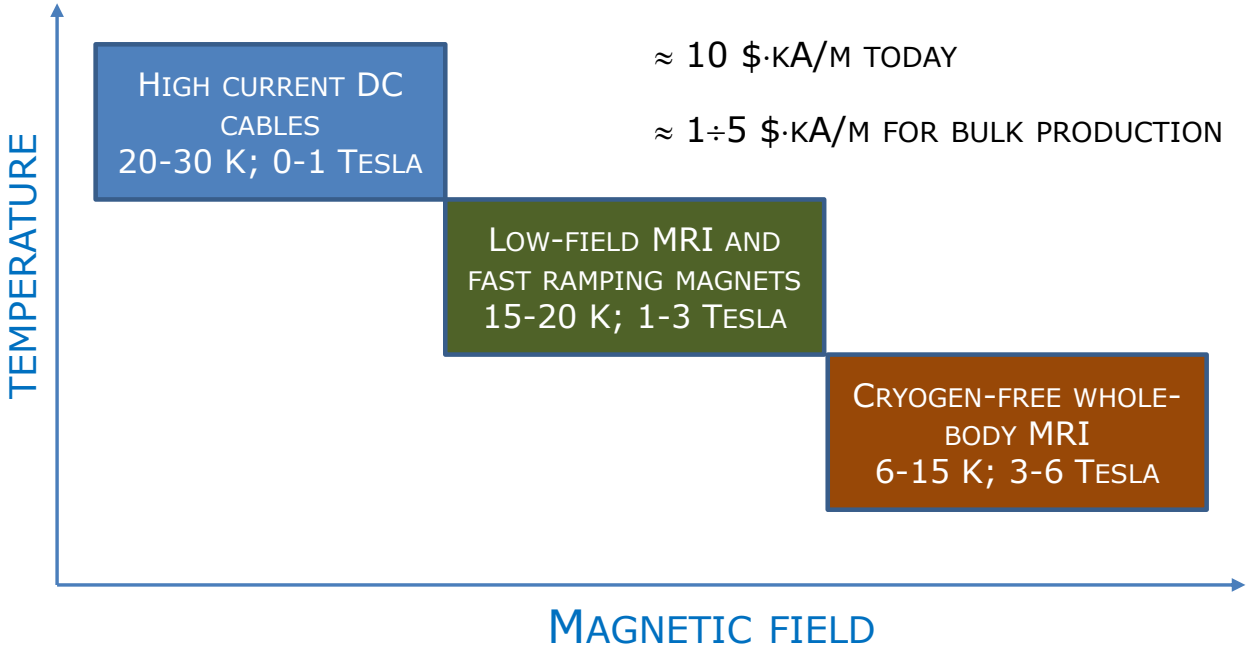
APPLICATION TARGETS FOR OUR MgB_2 R&D



≈ 10 $·kA/m TODAY

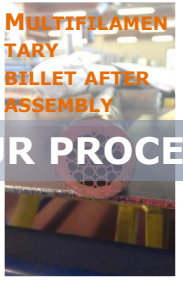
≈ 1÷5 $·kA/m FOR BULK PRODUCTION

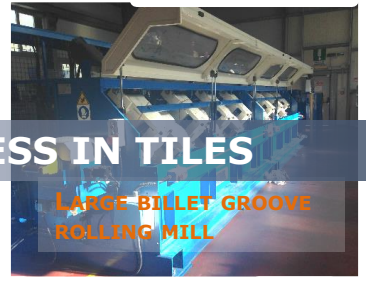
ASG SUPERCONDUCTORS

OUR EX-SITU PROCESSING

EX SITU MgB_2 PROCESS:

- REACTED MgB_2 POWDERS
- POWDERS HANDLED IN CONTROLLED ATMOSPHERE
- BILLET SIZE ABOUT 48 MM
- ELONGATION 1:20000
- SINGLE PIECE LENGTH UP TO 13 KM
- FINAL IN-LINE SINTERING
- SUPPLIED IN REACTED STATE





OUR PROCESS IN TILES

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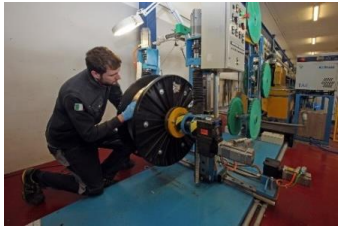
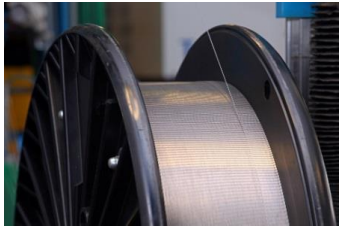
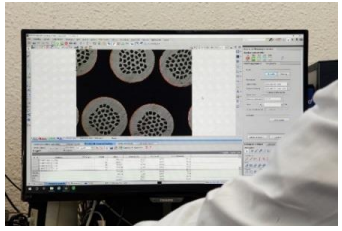
MgB_2 WIRES: OFF-THE-SHELF HTS TECHNOLOGY

EX-SITU MgB_2 WIRE PRODUCTION BASED ON INDUSTRIAL RAW MATERIALS

MAGNESIUM POWDERS
- Production of lightweight
- Alloys
- Pharma products
- Pyrotechnics, rockets

BORON POWDERS
- Airbags production
- Solid combustion
- Neutron capture

NICKEL-ALLOY PIPES
- Chemical plants
- Acid resistant tubing
- Alkaline resistant tubing

PRODUCT AND PROCESS KNOW-HOW & IP: Our ex-situ wires allow for React & Wind/Cable unlike other methods

PRODUCTION PLANT INSTALLED ENTIRELY IN GENOA, ITALY
All materials and manufacturing equipment available from Italy and nearby countries (easier procurement, maintenance, upgrade)

Ex-*situ* PRO-CONS

PRO

- Higher filament packing density (80-90%)
- React & Wind and React & Cabling straightforward
- Choice of desired electrical insulation
- Long lengths and uniformity
- Lower cost magnet manufacturing

CONS

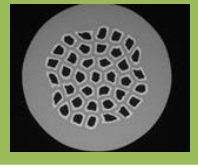
- Worse in-field performance than in-*situ*
- More complex wire manufacturing process than in-*situ* where most of the cold working is done by wire drawing

ASG SUPERCONDUCTORS

CABLES

MgB_2 ROUND WIRES FOR HIGH-CURRENT CABLES

Main characteristics

	Wire 1	Wire 2 - CERN	Wire 3	Wire 4
MgB_2 wire				
Diameter (mm)	1.3	1.0	1.5	1.5
Materials	Monel, Ni	Monel, Ni, Nb	Monel, Ni	Monel, Ni, Nb
MgB_2 volume fraction	17%	12%	30%	14%
I_C *(A)* @ 20 K and 1 T	500	350	> 650	> 650
I_C *(A)* @ 4.2 K and 3 T	450	250	> 700	600
Minimum $R_{bending}$ *(mm)*	125	100	200	150

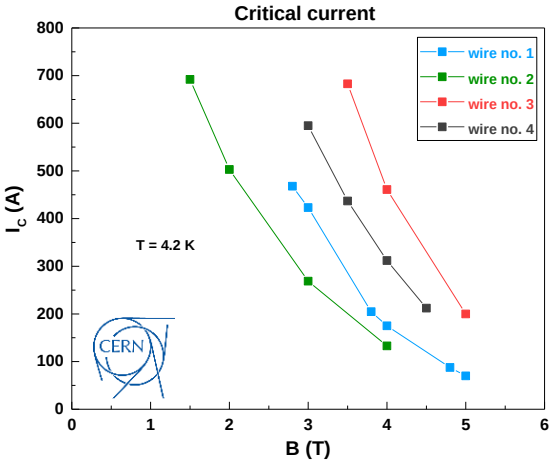
Record 13 km billet length
Production exceeded 1'000 km

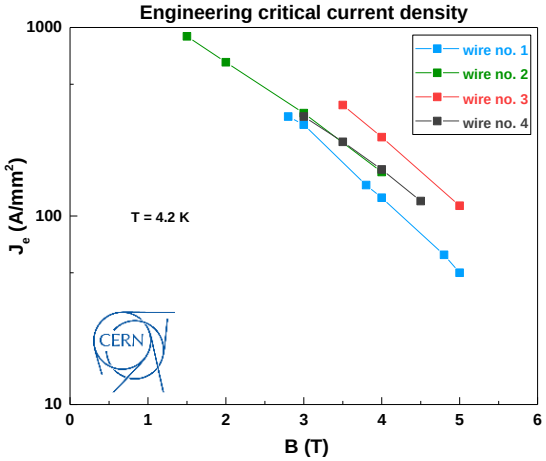
- STRAIGHT (VIRGIN) AND BENT WIRES HAVE BEEN THOROUGHLY STUDIED.
- TRANSPORT CURRENT MEASUREMENTS AT 4.2 K AND IN PARALLEL MAGNETIC FIELD IN THE RANGE 1.5 – 4.5 T.
- THE ELECTRICAL PERFORMANCE OF EACH WIRE LAYOUT HAS BEEN VALIDATED.
- THE MINIMUM BENDING RADIUS OF EACH WIRE LAYOUT WAS DEFINED.

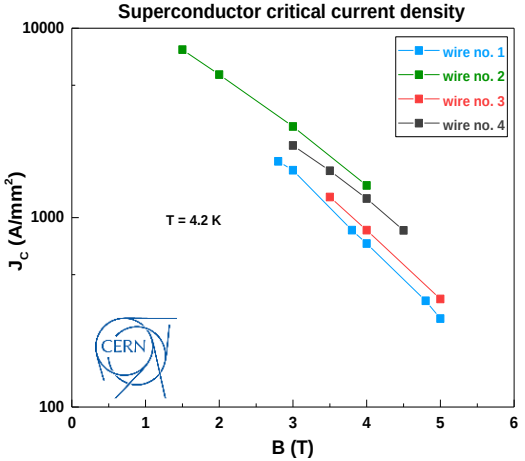
ELECTRICAL PERFORMANCE OF MgB_2 ROUND WIRES

Transport current measurements

- CRITICAL CURRENT
- ENGINEERING CRITICAL CURRENT DENSITY
- SUPERCONDUCTOR CRITICAL CURRENT DENSITY

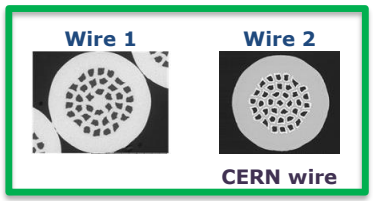






CONSIDERED PARAMETERS FOR THE DESIGN OF THE CABLE CONDUCTOR:

- RESULTS FROM TRANSPORT CURRENT MEASUREMENTS.
- MINIMUM BENDING RADIUS OF THE MgB_2 WIRE.
- QUALITY OF THE SUPERCONDUCTING FILAMENTS.
- COMPROMISE BETWEEN ELECTRICAL AND MECHANICAL PERFORMANCE.

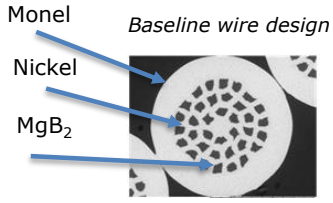


BEST WIRES FOR REACT & CABLING

Two wires selected for cabling

Wire 1

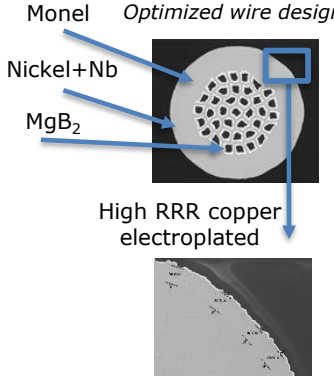
Baseline wire design



Wire 1	
Diameter (mm)	1.3
Filaments	36
MgB_2	17%
Monel	53%
Nickel	30%

Wire 2

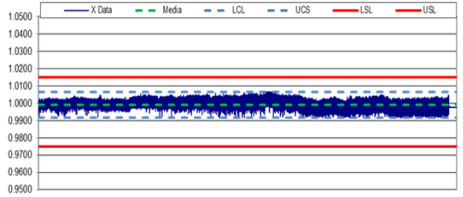
Optimized wire design



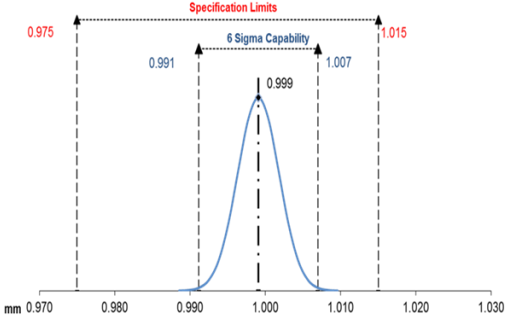
Wire 2	
Diameter (mm)	1
Filaments	37
MgB_2	12%
Monel	46%
Nickel	15%
Nb	13%
Copper	14%

STATISTICAL DISTRIBUTION OF THE WIRE DIAMETER

WITH VALUES BETWEEN THE SPECIFICATION LIMITS



Wire unit length about 3 km



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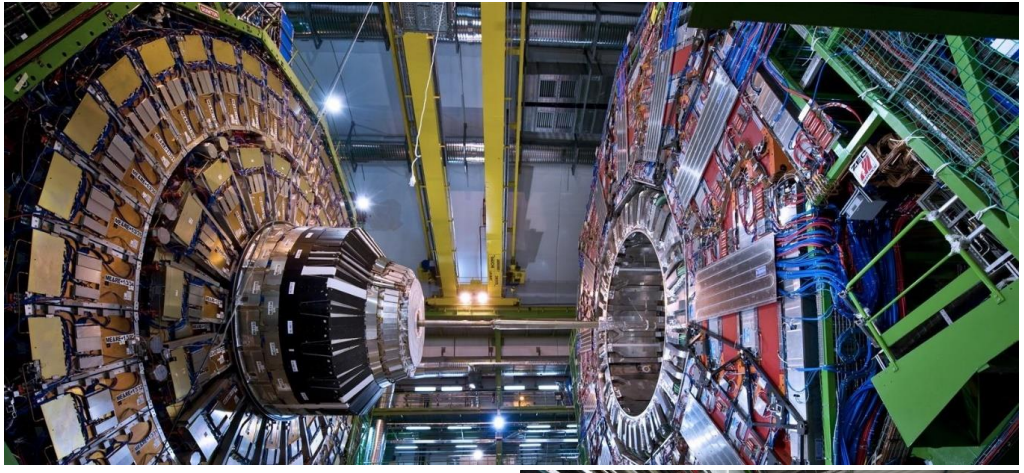
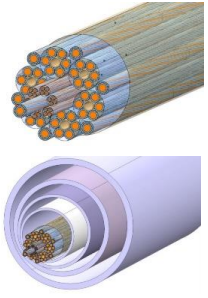
ASG MgB_2 CABLES POWERING CERN

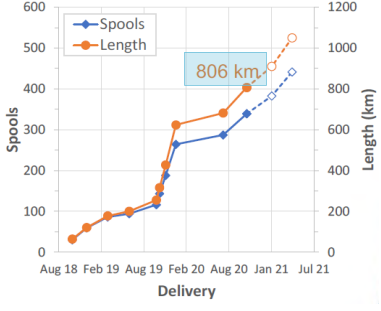
CERN has FULLY QUALIFIED MgB_2 CABLES and all components meet the acceptance criteria

SERIES PRODUCTION ongoing

Full wire delivery meanwhile completed with 6 month in advance!







120 kA, 5 kV

TARGET ACHIEVED

↓

600 MW compact MgB_2 power cable qualified!

ASG SUPERCONDUCTORS

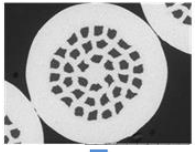
CABLE CONDUCTOR: DESIGN AND PERFORMANCE

Fault tolerant cable configuration: MgB_2 cable conductor designs

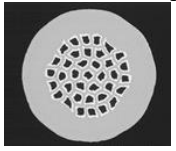
Nominal operating requirements

DC operation	
Current rating	10 kA
Voltage rating of the cable system	320 kV
Power rating of the cable system	3.2 GW
Operating temperature	20 K
Fault current	35 kA during 100 ms

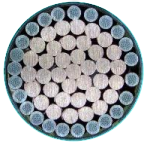
Wire 1
Baseline wire design



Wire 2
Optimized wire design



Cable #1

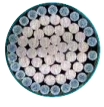


Cable #2

Cable #1

18 MgB_2 wires
I_C = 14200 A @ 20 K & S.F. 0.7 T
I_{op}/I_C = 0.70
Insulated cable diameter = 9.9 mm

Cable #2



24 MgB_2 wires
I_C = 12960 A @ 20 K & S.F. 0.7 T
I_{op}/I_C = 0.77
Insulated cable diameter = 9.9 mm

Industrial cabling at Nexans, Cortaillod

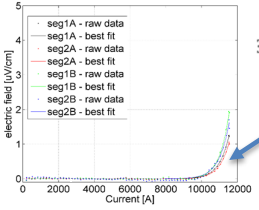
CABLE CONDUCTOR: DESIGN AND PERFORMANCE

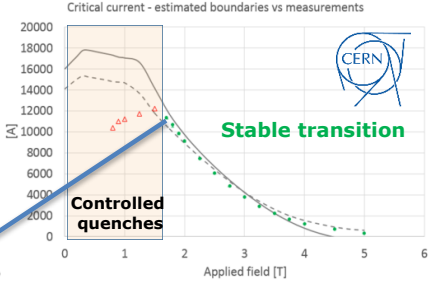
Critical current measurements at 4.2 K

- I_C measurements of 2 m long MgB_2 cable in FRESCA test station.
- Tests carried out at 4.2 K and in perpendicular field up to 5 T.

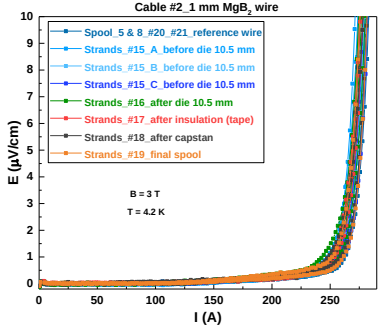
Cable #1

Validation of the cabling process

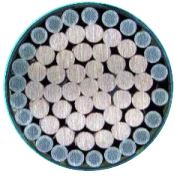




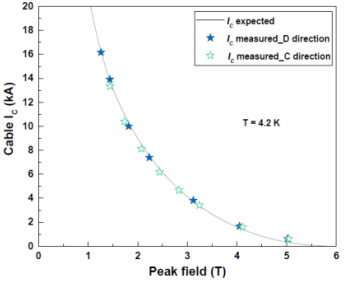
Dummy Cable #2



Cable #2



Validation of the cabling process

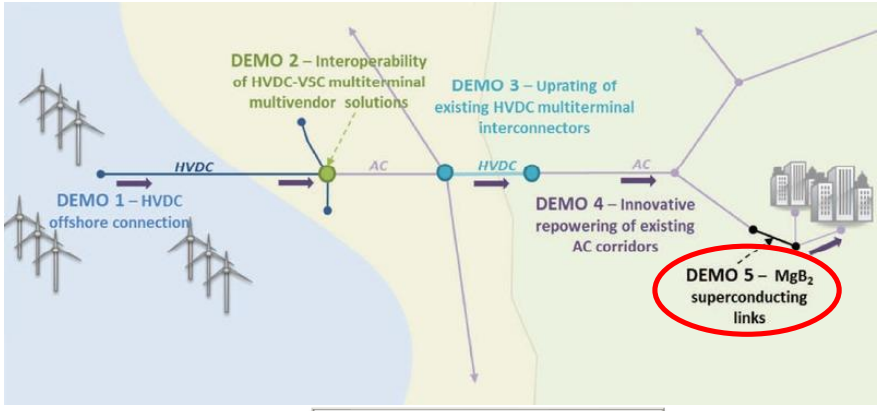


- Tests carried out at 4.2 K and in parallel field up to 3 T.

ASG SUPERCONDUCTORS

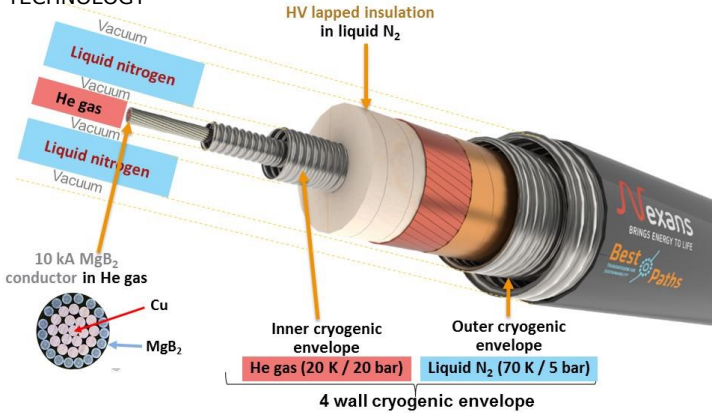
A PROJECT TO OVERCOME THE CHALLENGES OF INTEGRATING RENEWABLES

BEST PATHS PROJECT: THE LARGEST PROJECT EVER SUPPORTED BY THE EUROPEAN COMMISSION RDD FRAMEWORK PROGRAMS WITHIN THE FIELD OF POWER GRIDS



Demo 5 budget: 6.7 M€
EU contribution: 4 M€

- DEMONSTRATE FULL-SCALE 3 GW CLASS HVDC SUPERCONDUCTING CABLE SYSTEM OPERATING AT 320 KV AND 10 KA
- VALIDATE THE NOVEL MgB_2 SUPERCONDUCTOR FOR HIGH-POWER ELECTRICITY TRANSFER
- PROVIDE GUIDANCE ON TECHNICAL ASPECTS, ECONOMIC VIABILITY, AND ENVIRONMENTAL IMPACT OF THIS INNOVATIVE TECHNOLOGY

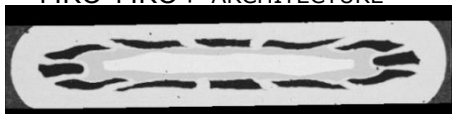


ASG SUPERCONDUCTORS

MAGNETS

MgB_2 Wires for magnet application

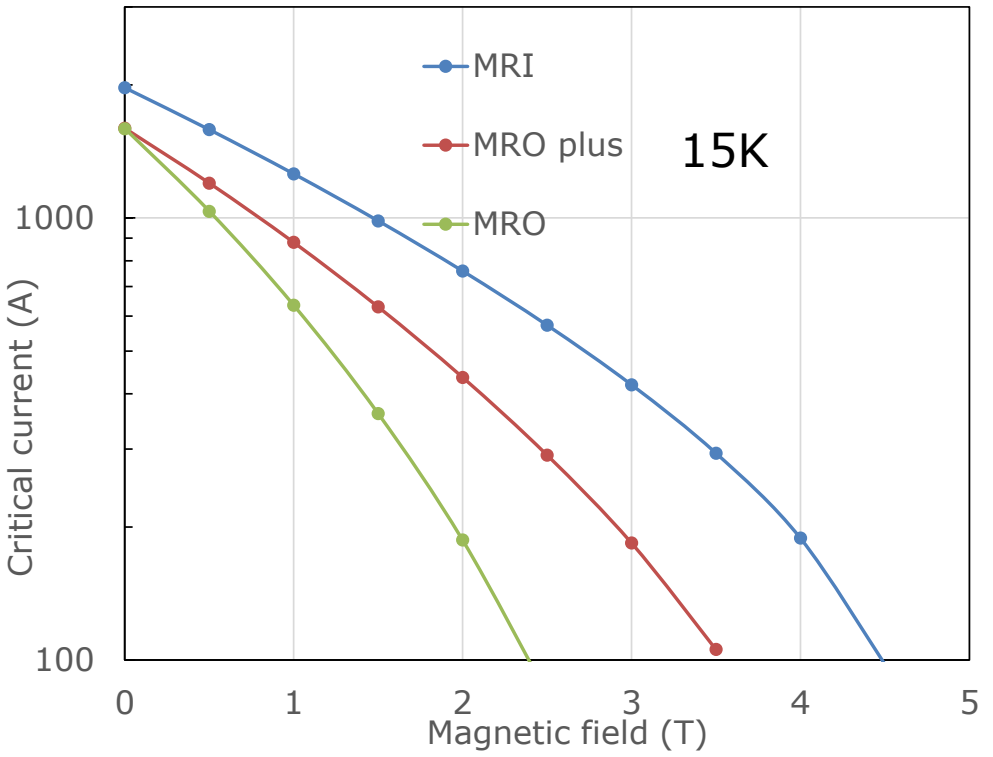
MRO-MRO+ architecture



Feature	Value
Filaments number	12
Overall bare conductor dimensions [mm]	3.67 X 0.65 mm
Overall Area [mm²]	2.2 mm²
MgB_2 area [mm² and %]	0.26 mm² - 12%
Ni area [mm² and %]	1.39 mm² – 63%
Iron area [mm² and %]	0.22 mm² – 10%
Copper area [mm² and %]	0.33 mm² – 15%
Twist pitch [mm]	750 mm
Overall dimensions with polyester insulation	3.79 X 0.77 mm
Minimum bending diameter easy way	150 mm
Minimum bending diameter hard way	1200 mm
Typical piece length	4 km

MRO / MRO+ differ by MgB_2 doping

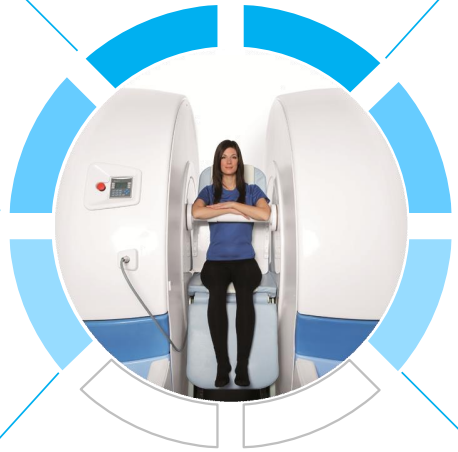
MRI is round with filling factor of 26%



ASG SUPERCONDUCTORS

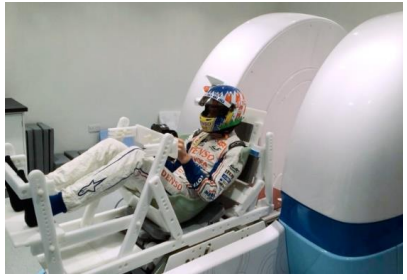
MR-OPEN FEATURES

- REAL UPRIGHT MRI
- LARGE GAP MAY HOST MORE PATIENTS
- FULLY CRYOGEN-FREE SUPERCONDUCTING
- IDEAL FOR CLAUSTROPHOBIC PATIENTS
- MAY ROTATE: IMAGE GUIDED PROTON/RADIATION THERAPY POSSIBLE
- MORE FREEDOM FOR SPECIFIC APPLICATIONS



MgB_2-BASED MRI INSTALLED GLOBALLY HAVE ALREADY EXCEEDED 1'000'000 HOURS OF OPERATION!

Field Strength	0.5 T
Magnet Type	dry
Lateral gap	56 cm
Gradients max intensity	20 mT/m
Rise Time	0.6 msec
Slew Rate	33 mT/m/msec
Digital Spectrometer	8 ch receivers
Maximun Field of View	36 cm



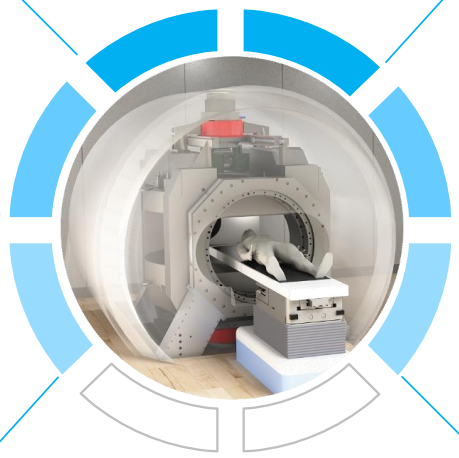
12 KM MgB_2 WIRE EACH

EXPANDING INSTALLED BASE

ASG SUPERCONDUCTORS

LINAC MR FEATURES

- IMPROVED TREATMENT OUTCOME
- NO INTERFERENCES (between MRI and Linac)
- MR-GUIDED RADIOTHERAPY
- TOTAL SAFETY
- COST-EFFECTIVE INSTALLATION & EASY TO MAINTAIN
- UNIQUE LARGE PATIENT OPENING



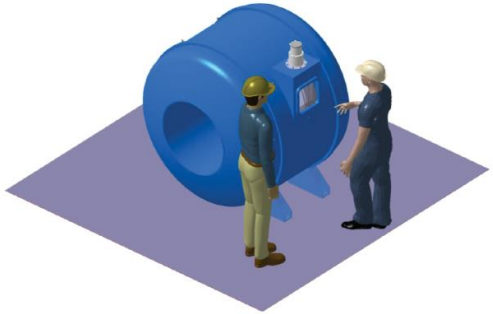
MgB_2-BASED MRI USED TO GUIDE PARTICLE AND RADIATION CANCER THERAPY BEAMS

ASG SUPERCONDUCTORS

EXTREME 1 T MRI MAGNET SOLUTIONS

HEAD SCANNER

FAST RAMPING INTRA-OPERATIVE 1T/700 MRI



- COMPACT AND LIGHTWEIGHT SCANNER FOR NEUROSURGEONS
- MOVABLE AND CRYOGENIC-FREE FOR INSTALLATION AND USE IN SURGERY ROOMS
- FULLY CRYOGEN-FREE SUPERCONDUCTING MgB_2 SOLUTION
- ULTRA-FAST RAMPING TO BE UP TO FIELD IN MINUTES

TOTAL BODY

LIGHTWEIGHT & PORTABLE 1T/800 MRI

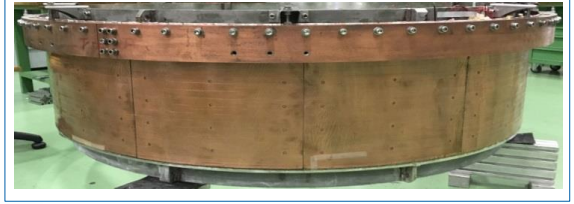
- ULTRA LIGHT-WEIGHT SCANNER
- FULLY CRYOGEN-FREE SUPERCONDUCTING MgB_2 SOLUTION
- ROBUST AND STABLE DESIGN
- LOW FIELD HOMOGENEITY COMPENSATED WITH ADVANCED IMAGING AND PROCESSING TECHNIQUES

ASG 36kV SFCL Construction

1 AC coils around iron cores

2 AC coils in oil tank

3 Superconducting DC bias coil in manufacturing



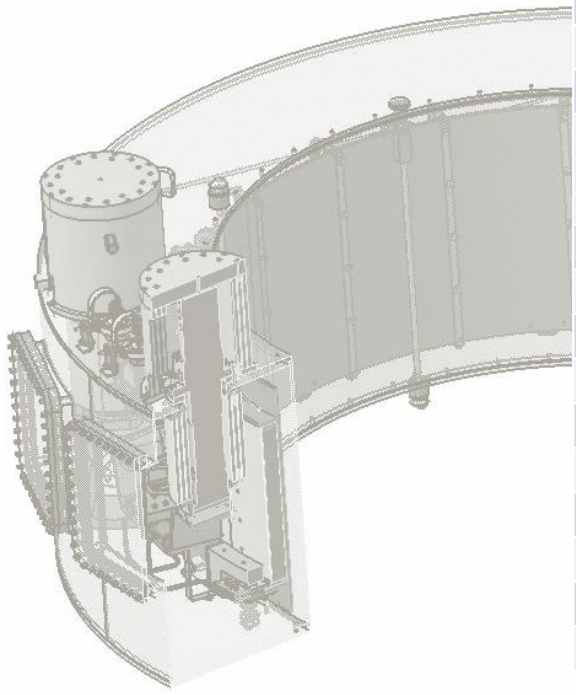
50 km total MgB_2 wire amount in 3.2 km unit piece length

4 Fitting AC part inside DC bias coils

5 Testing of device in IPH Berlin

ASG SUPERCONDUCTORS

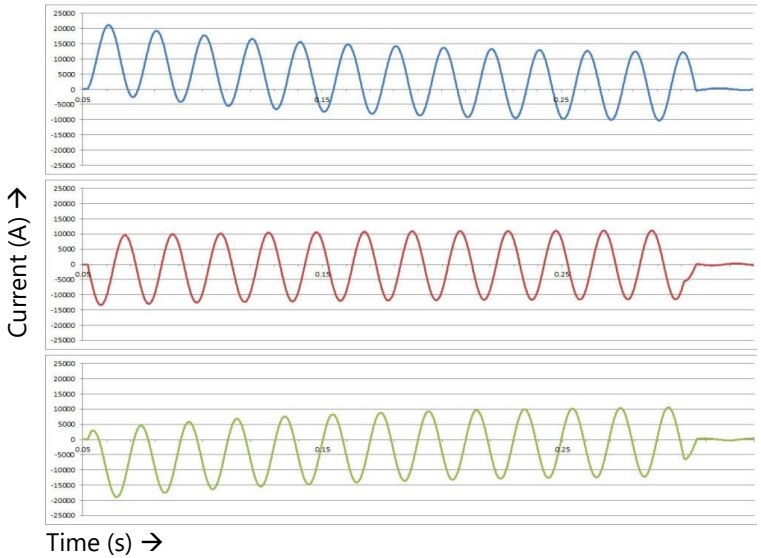
ASG 36kV SFCL Specification



Parameter	Requirement
Rated voltage	36kV
Line frequency	50Hz
Line voltage at fault level below	33kV
Maximum allowable steady state voltage drop at rated continuous normal current (800A)	600V rms
Lightning impulse voltage withstand level	170kV; 1.2/50µs
Power frequency voltage withstand level	70 kV for 1 minute
Continuous normal current	$800A_{rms}$
Maximum normal current (magnitude and duration)	$1400A_{rms}$ / 15minutes
Prospective unlimited peak fault current	$21.0kA_{peak}$
Peak limited current	$13.8kA_{peak}$
Prospective unlimited symmetrical fault current	$8.0kA_{rms}$
Symmetrical limited current	$5.0kA_{rms}$
Fault duration	Up to 3 seconds
Load power factor	0.98

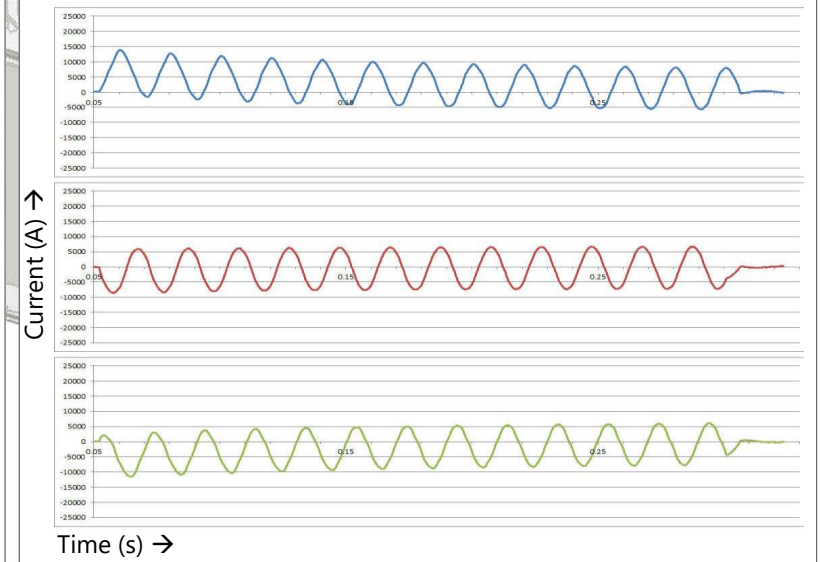
Short Circuit Tests

Prospective Currents 21kA Peak / 8kA rms Symmetrical



No SFCL

Limited Currents 13.8kA Peak / 5kA rms Symmetrical

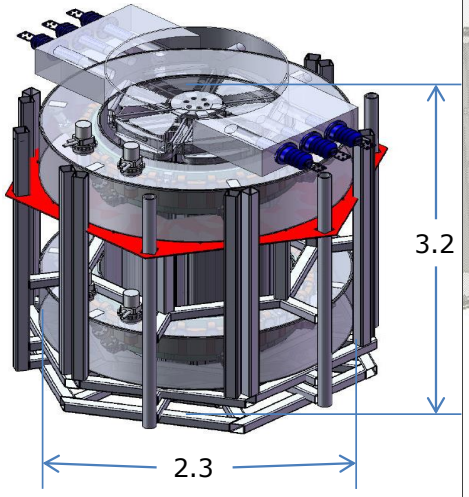


With SFCL

ASG SUPERCONDUCTORS

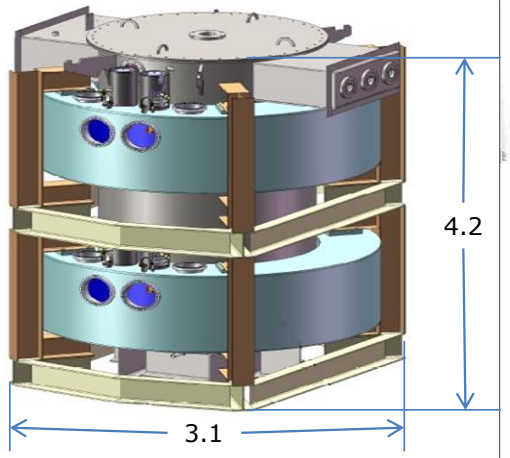
DESIGN FLEXIBILITY

By modifying the size of the AC and DC components of the SFCL, we can offer a wide range of current and voltage ratings:



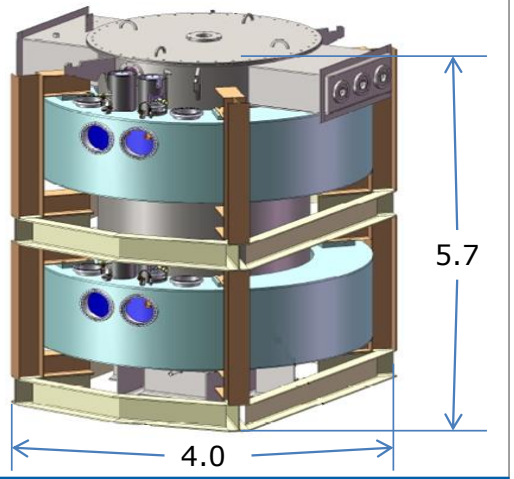
11KV FCL

WEIGHT 15 T



72.5KV FCL

WEIGHT 50 T



145KV FCL

WEIGHT 100 T

ASG SUPERCONDUCTORS

COMMERCIAL MgB_2 INDUCTION HEATER

시작품 제작완료 및 테스트 성공

SUPERCOIL ASG SUPERCONDUCTORS

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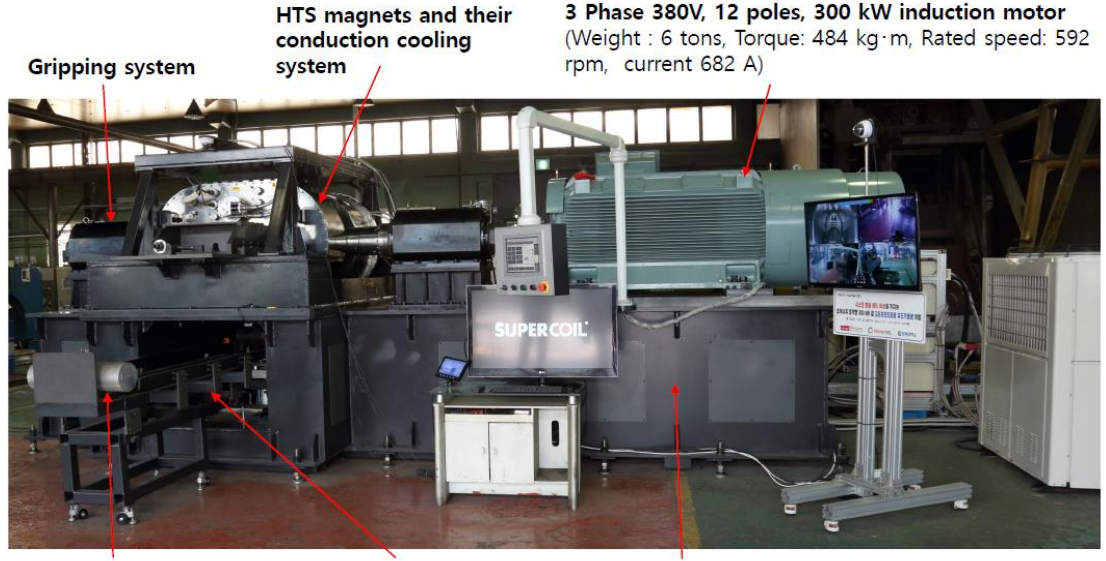
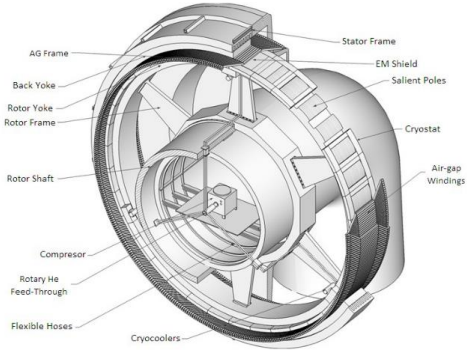
Super coil



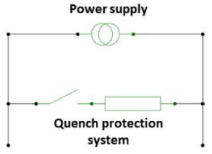
AND MUCH MORE...

A 10 MW CONCEPT: SUPRAPOWER

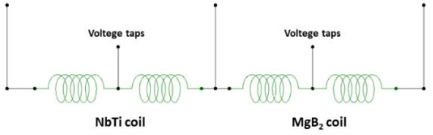


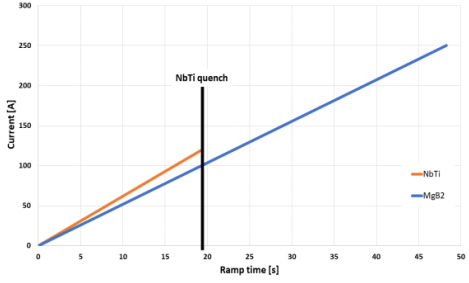
- Synchronous salient pole, direct drive
- 10 MW, 8.1 rpm, 11.8 MNm
- MgB_2 superconducting field coils
- Cryogen free cooling system (reduce maintenance requirements)
- Modular Cryostats
- 48 warm iron poles
- Air-gap armature winding
- 1.5 T of induction peak value
- Airgap shear stress of 112 kPa
- 10.1 m air-gap diameter,
- 0.74 m stack length

NbTi and MgB_2 identical coils, comparison of thermal behavior during fast field variation



The MgB_2 coil has been successfully ramped up to full field of about 2 Tesla in less than 50 seconds; the NbTi coil has quenched at a fraction of the current





CONCLUSIONS AND AKNOWLEDGEMENTS

- The progress in application of MgB_2 wires we made in the past decade has been very solid
- Medical, industrial and grid devices have successfully passed prototyping phase
- We believe that the next decade will see the MgB_2 wires in many more commercial applications
- MgB_2 will contribute to the carbon neutral economy!
- **Thank you Prof. Akimitsu and team!**

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