TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Elektrotechnik und Informationstechnik Institut für Elektrische Energieversorgung und Hochspannungstechnik

Investigations on Different Joining Techniques Regarding Current-carrying Joints with Normal Conducting Material and YBCO Coated Conductors at low temperatures

IEEH

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Braunschweiger Supraleiterseminar
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DRESDEN concept
Exzellenz aus Wissenschaft und Kultur

Outline

Motivation
- The inductive shielded superconducting fault current limiter
- Objective of investigation

Conductor type
- Overview of normal and YBCO coated conductors
- Joining techniques

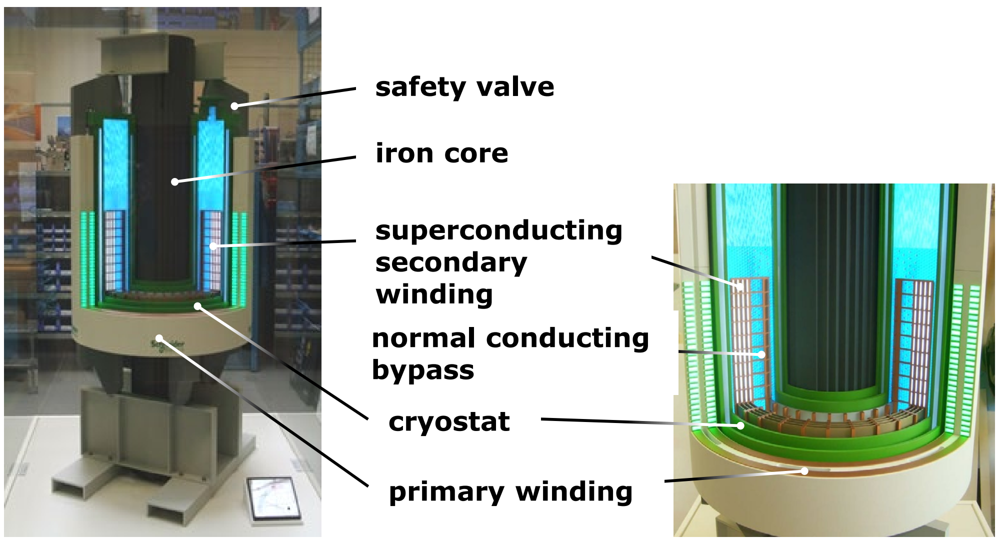
Electrical Characterisation
- Measurement principle
- Test results

Evaluation of results

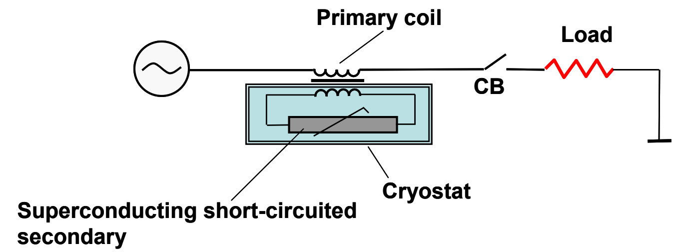
Conclusion and outlook

Motivation

The inductive shielded superconducting fault current limiter (iSFCL)



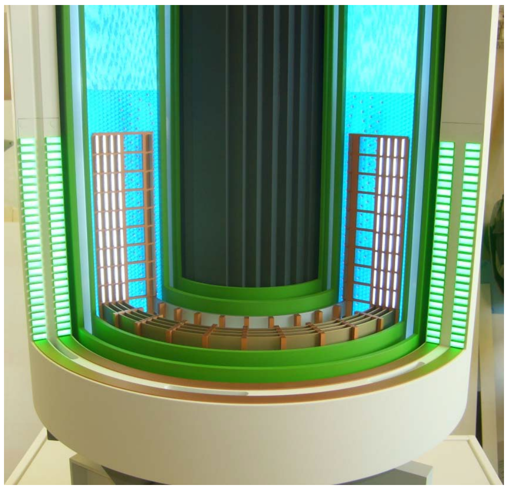
Sectional view of an iSFCL demonstrator



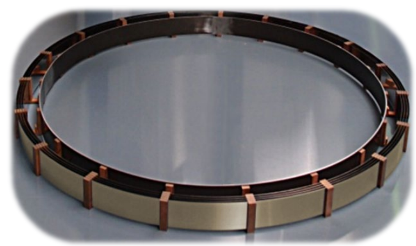
simplified diagram of network integration

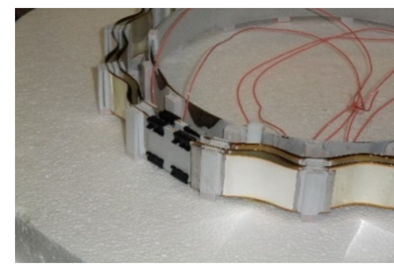
Motivation

Objective of investigation



Circular, parallel arrangement of YBCO coated conductors and normal conducting bypass





⇒ investigations on current-carrying joints at temperatures of boiling liquid nitrogen (LN_2 , -195,8°C) necessary

⇒ analysis of different joining techniques as alternatives to cadmium and lead joints in industrial applications

⇒ measurement of electrical resistance R (in µΩ) and power losses P_v (in W)

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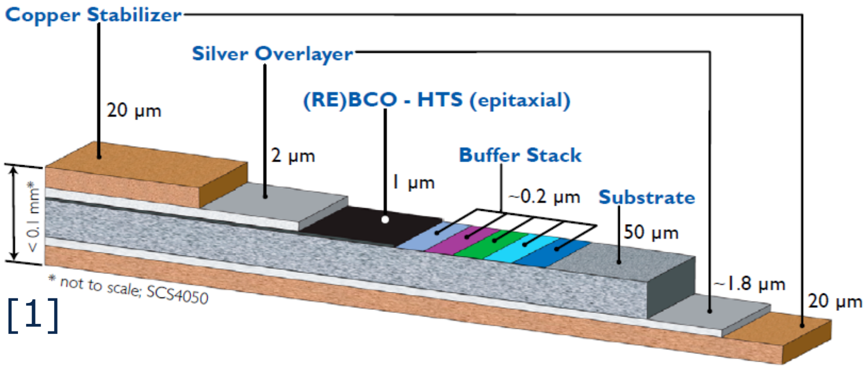
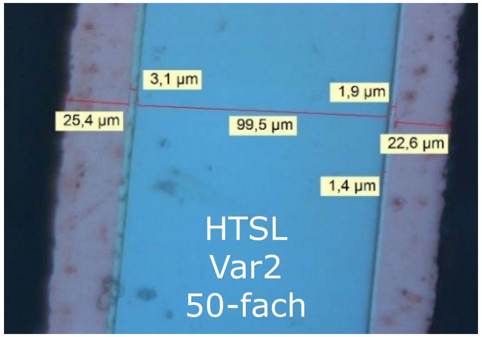
Conductor type

Overview of normal and YBCO coated conductors

Comparison of a schematic and real stack of layers of a YBCO coated conductor



[1]



	Variante	Substrate	Width	Thick-ness	Layer		Sur-face	Quench-current
		h / µm	*b* / mm	*d* / µm	Cu	Ag		*Ic* / A
HTSL	Var1	75	12	190	100 µm	8 µm	Ag	250
	Var2	100	12	150	40 µm	4 µm	Cu	300
	Var3	100	12	110		4 µm	Ag	280
NL	Cu		12	100	100 µm		Cu	
	Ag		12	110	100 µm	4 µm	Ag	

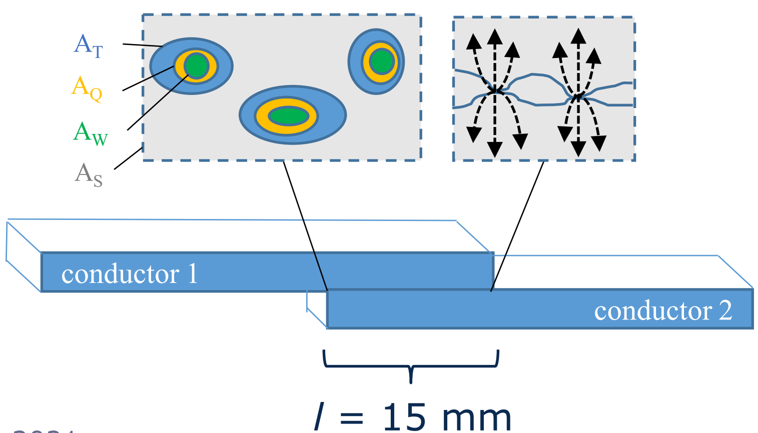
Conductor type

Joining techniques

- Force-fit and substance-to-substance bond
- Joining techniques
  - Clamping
  - Adhesive bonding
  - RMS-soldering

EU-regulations RoHS and REACH are limiting the industrial application of lead and cadmium [2]

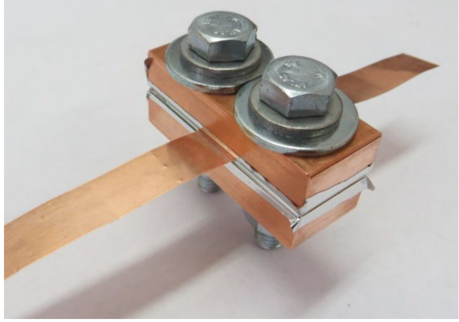
- While joining, the optimum between joint resistance R_V, tensile force F_Z and conductor stress was investigated



Conductor type

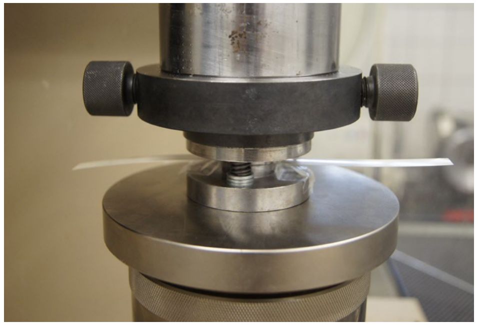
Joining techniques

Clamping



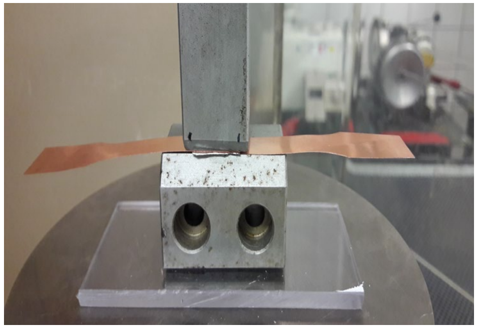
- The clamp consists of two copper blocks whose sides, were covered with an insulating foil
- This prevents the electrical contact between block and conductors
- The optimum torque M = 12,5 Nm

Adhesive Bonding



- A two-component nonconductive room temperature curing adhesive was used
- A mating force of F = 3.5 kN was found as optimum

RMS-soldering



- The thermal energy is provided by activating the atomic diffusion in a reactive nanometer multilayer system (Al-Ni)
- RMS films with an 80 µm Al-Ni RMS stack with Sn solder were used
- The optimum was found with a mating force of F = 3.5 kN [3]

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Electrical Characterisation

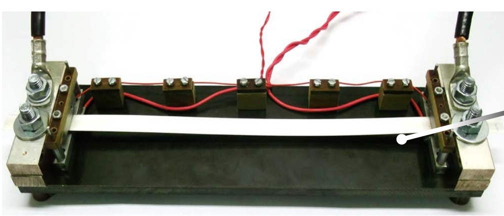
Measurement Principle

Variable transformer

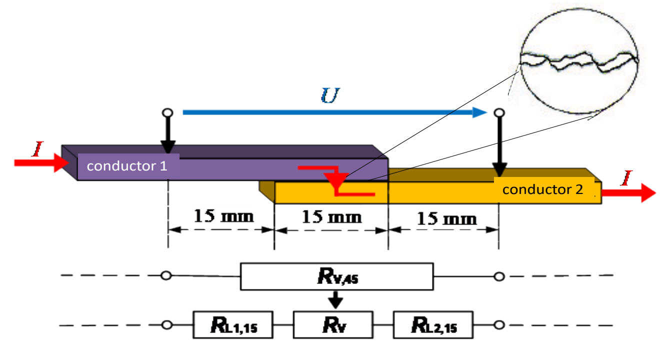
High current transformer

contactor

LN_2 tank with test object



Determination of the electrical material and joint resistance R_M resp. R_V:



$$\boxed{R_V = R_{V,45} - (R_{M1,15} + R_{M2,15})}$$

=> Inductive current infeed via high current transformer

Electrical Characterisation

Test results

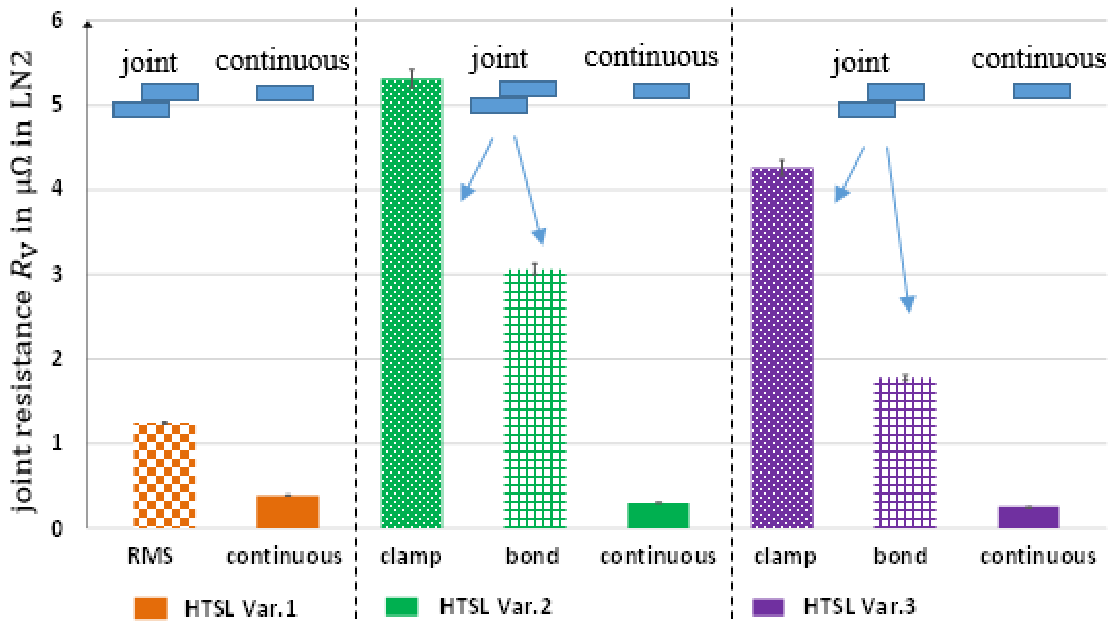
Variants of investigated joints of NL- and HTSL-conductors in liquid nitrogen (LN_2)

Joining technique/ Material combination		clamping	bonding	RMS-soldering
		LN_2	LN_2	LN_2
HTSL-joints	Var1 – Var1	-	-	x
	Var2 – Var2	x	x	-
	Var3 – Var3	x	x	-
HTSL-NL-joints	Cu-Var1	-	-	x
	Ag-Var1	-	-	x
	Cu-Var2	x	x	-
	Ag-Var3	x	x	-

Electrical Characterisation

Test results

AC joint resistances R_V of YBCO coated conductors compared to the resistance $R_{M,15}$ of non-jointed HTSL conductors

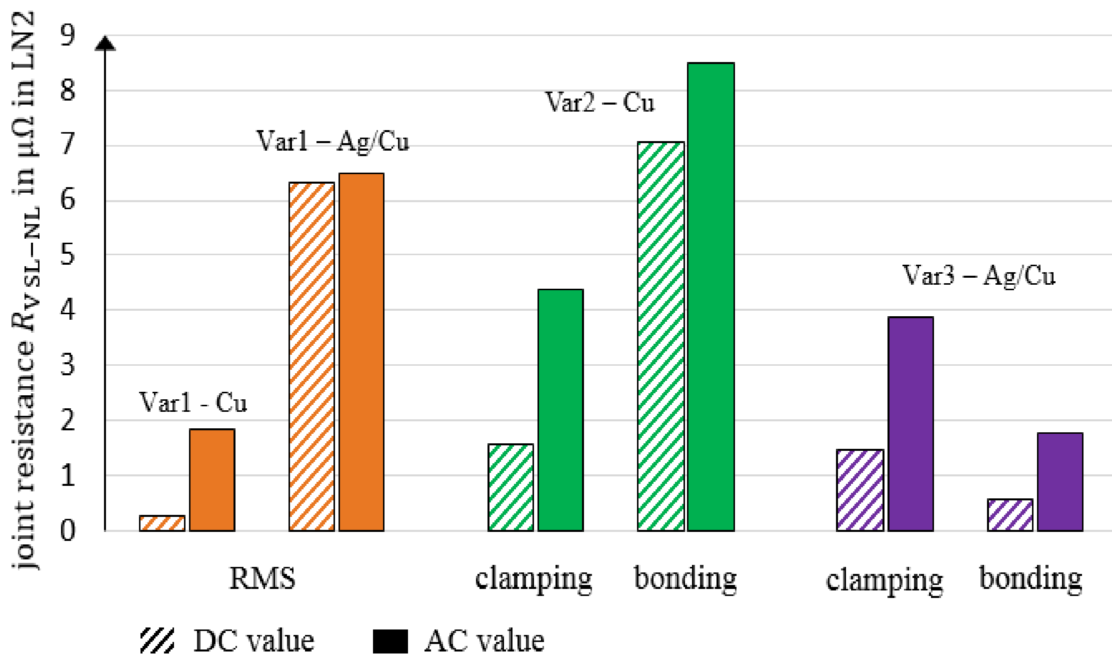


Test current
I_{AC} = 100 A

Electrical Characterisation

Test results

Comparison of DC and AC joint resistances $R_{V,SL\text{-}NL}$ of clamped, adhesive bonded and RMS soldered conductors

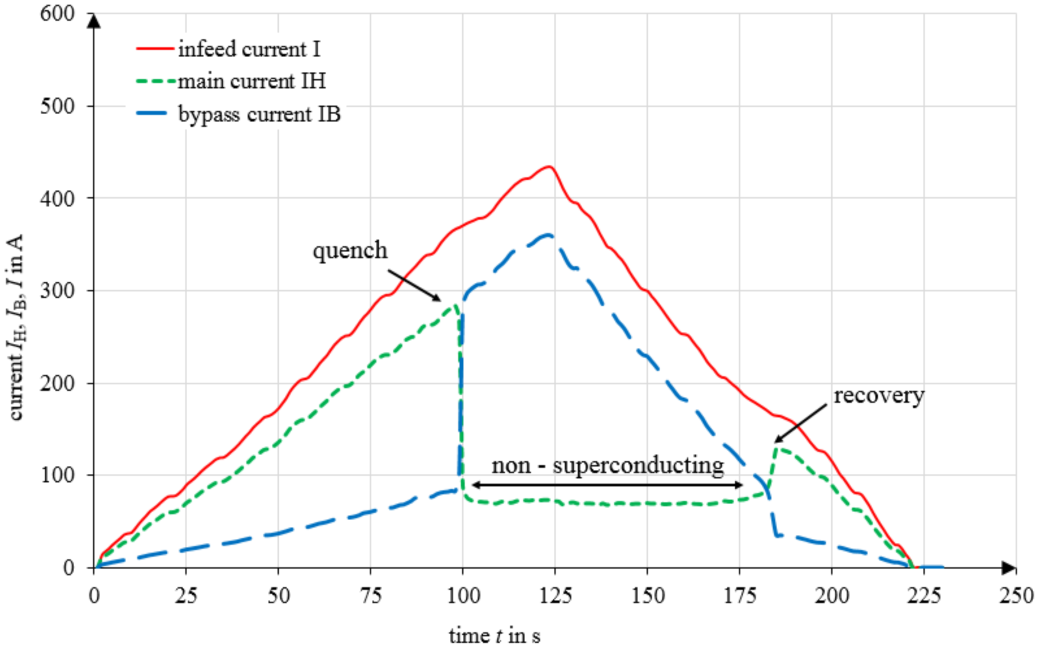


Test current
$I_{DC,\,AC}$ = 100 A

Electrical Characterisation

Test results

Behaviour of a clamped superconducting joint in parallel to a normal conducting copper bypass



$$I = I_B + I_H$$

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Evaluation of electrical parameters

material	continuous conductors		clamping		adhesive bonding		RMS soldering	
	$\hat{I}$ = 100A	Quench	$\hat{I}$ = 100 A	Quench	$\hat{I}$ = 100 A	Quench	$\hat{I}$ = 100 A	Quench
values in mW	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$
Var1	6	45	-	-	-	-	-	-
Var2	4	78	-	-	-	-	-	-
Var3	3	51	-	-	-	-	-	-
Var1–Var1	-	-	-	-	-	-	**10**	**69**
Var2–Var2	-	-	28	363	17	255	-	-
Var3–Var3	-	-	18	170	**10**	**112**	-	-

Overview of the measured power losses P_V of YBCO continuous and joint coated conductors

material	continuous conductors		clamping		adhesive bonding		RMS soldering	
	$\hat{I}$ = 100A	Quench	$\hat{I}$ = 100 A	Quench	$\hat{I}$ = 100 A	Quench	$\hat{I}$ = 100 A	Quench
values in mW	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$	$P_{V\,AC}$
Cu-Var1	-	-	-	-	-	-	**153**	**956**
Ag-Var1	-	-	-	-	-	-	**160**	**1072**
Cu-Var2	-	-	160	1970	424	5514	-	-
Ag-Var3	-	-	140	1240	215	2030	-	-

Overview of the measured power losses P_V of YBCO coated conductors and normal conductors

- The quality factor of YBCO coated conductors can't be determined, as superconductors don't show a material resistance R_M
- The measured resistance R_{AC} is related to the power loss P_V during current carrying process

=> Best results were reached with the RMS soldering technique, as it leads to a metallic continuously joint

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Conclusion

- 3 different cadmium and lead free joining techniques for joining normal and YBCO coated conductors were qualified regarding their principle application at low temperatures in LN_2 environment
- A test set-up suitable for low temperature investigations was established
- The resistance of these joining techniques was investigated for DC- and AC-application
- The target of a low joining resistance R_V was reached by optimising the joining parameters
- The joints were applied in a parallel bypass circuit and tested related to their commutation behaviour. At the example of a clamped joint installed in the bypass circuit the proper functioning was shown.

Outlook

As electrical devices are installed for up to 30 years in our networks, the long term behaviour of the qualified joining techniques should be further investigated:

- Investigation of the long term behaviour of the qualified joining techniques in liquid nitrogen LN_2

  => continuous current tests in a closed cryostate

- Are the ageing effects known at room temperature the same as in LN_2?

- The parallel bypass circuit has to be investigated also for AC application

  => Examination of alternating magnetic fields

- Analysis of the heating behaviour in HTSL conductors, to evaluate the current distribution for higher infeed currents

  => simulation in a thermal network

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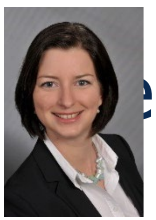
Kontakt



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»Wissen schafft Brücken.«

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Literatur

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[2] ZVEI.[Online] http://www.zvei.org/Themen/GesellschaftlundUmwelt/Seiten/RoHS-Richtlinie.aspx, (08.02.2016)

[3] M. Rühl, G. Dietrich, E. Pflug, S. Braun, A. Leson: Heat and Mass transfer in reactive multilayer systems, Comsol Conference, Milan, 2012