

# **New Parametric Current Transformer**

## **User's Manual**

Rev. 2.2

## Record of updates

Version	Date	Updates performed
2.0	03/2018	Review of the full manual. Obsoletes all former releases
2.1	12/2019	Modification of the cover page and creation of the distributors' page
2.2	05/2021	Update of the "NPCT cassette front panel" picture Update of the "Installation over vacuum chamber" picture Update of the interconnect cable datasheets Removal of connection allocation diagram in the "Interconnect cable and pairs allocation" chapter Option descriptions update

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## **INITIAL INSPECTION**

It is recommended that the shipment be inspected immediately upon delivery. If it is damaged in any way, contact Bergoz Instrumentation or your local distributor. The content of the shipment should be compared to the items listed on the invoice. Any discrepancy should be notified to Bergoz Instrumentation or its local distributor immediately. Unless promptly notified, Bergoz Instrumentation will not be responsible for such discrepancies.

## **WARRANTY**

Bergoz Instrumentation warrants its beam current monitors to operate within specifications under normal use for a period of 12 months from the date of shipment. Spares, repairs and replacement parts are warranted for 90 days. Products not manufactured by Bergoz Instrumentation are covered solely by the warranty of the original manufacturer. In exercising this warranty, Bergoz Instrumentation will repair, or at its option, replace any product returned to Bergoz Instrumentation or its local distributor within the warranty period, provided that the warrantor's examination discloses that the product is defective due to workmanship or materials and that the defect has not been caused by misuse, neglect, accident or abnormal conditions or operations. Damages caused by ionizing radiations are specifically excluded from the warranty. Bergoz Instrumentation and its local distributors shall not be responsible for any consequential, incidental or special damages.

## **ASSISTANCE**

Assistance in installation, use or calibration of Bergoz Instrumentation beam current monitors is available from Bergoz Instrumentation, 01630 Saint Genis Pouilly, France. It is recommended to send a detailed description of the problem by email to info@bergoz.com.

## **SERVICE PROCEDURE**

Products requiring maintenance should be returned to Bergoz Instrumentation or its local distributor. Bergoz Instrumentation will repair or replace any product under warranty at no charge. The purchaser is only responsible for transportation charges.

For products in need of repair after the warranty period, the customer must provide a purchase order before repairs can be initiated. Bergoz Instrumentation can issue fixed price quotations for most repairs. However, depending on the damage, it may be necessary to return the equipment to Bergoz Instrumentation to assess the cost of repair.

## **RETURN PROCEDURE**

All products returned for repair should include a detailed description of the defect or failure, name and fax number of the user. Contact Bergoz Instrumentation or your local distributor to determine where to return the product. Returns must be notified by mail prior to shipment.

Return should be made prepaid. Bergoz Instrumentation will not accept freight-collect shipment. Shipment should be made via UPS, FedEx or DHL. Within Europe, the transportation service offered by the Post Offices "EMS" (Chronopost, Datapost, etc.) can be used. The delivery charges or customs clearance charges arising from the use of other carriers will be charged to the customer.

## **SAFETY INSTRUCTIONS**

This instrument is operated from the mains power supply. For safe operation, it must be grounded by way of the grounding conductor in the power cord. Use only the fuse specified. Do not remove cover panels while the instrument is powered. Do not operate the instrument without the cover panels properly installed.

Chassis originally shipped to U.S. or Canada feature AC mains power entry modules where the Phase is fused and the Neutral unfused, as is the rule.

Chassis to other destinations but U.S. and Canada feature AC mains power entry modules where both Phase and Neutral are fused.

When a chassis with unfused Neutral is used outside the U.S. and Canada, both Phase and Neutral should be fused:

The Power entry module must be opened, the Neutral fuse must be removed, the fuse holder must be flipped; its reverse side presents two slots where two new fuses must be inserted, one in each slot.

The fuses rating must be same as the Neutral fuse that was removed.

The Toroid sensor contains materials such as cobalt and iron. Those materials may become radioactive when exposed to high energy particle beams. Follow applicable radiation-safety procedures when the Toroid sensor must be moved out of controlled areas.

## **LEGAL RIGHTS**

The Parametric Current Transformer was developed by Dipl. Ing. Klaus B. Unser of the LEP Division at CERN in the framework of the Collaboration Agreement N° K017/LEP between CERN and BERGOZ. This agreement grants Bergoz Instrumentation the right to commercialize the resulting technology.

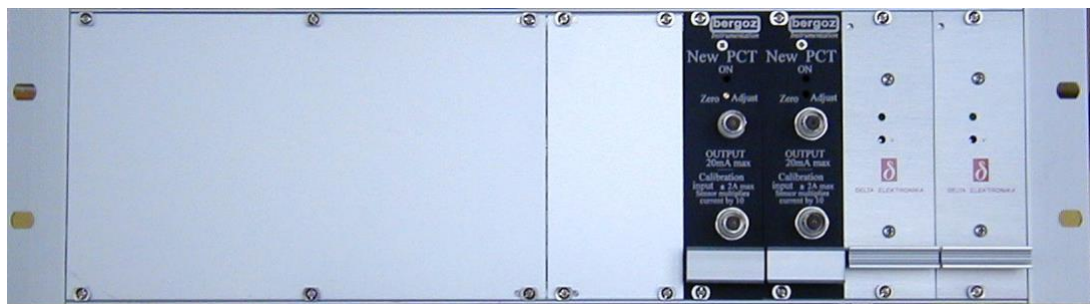
Publication:

The Parametric Current Transformer, a beam current developed for LEP, by Klaus B. Unser  
<http://www.bergoz.com/sites/www.bergoz.com/files/unser-pct>

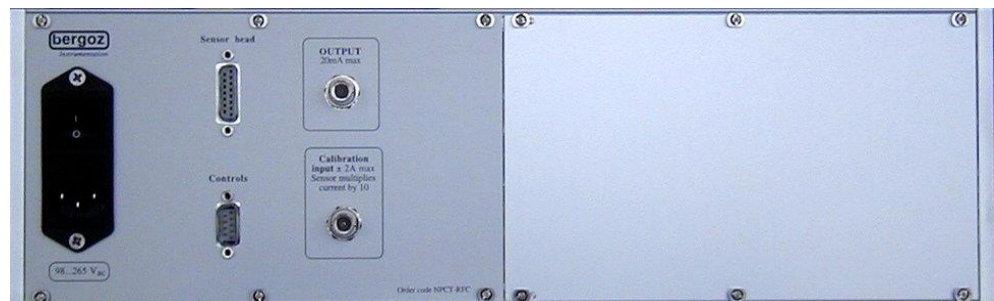


## NPCT SET

### Front view



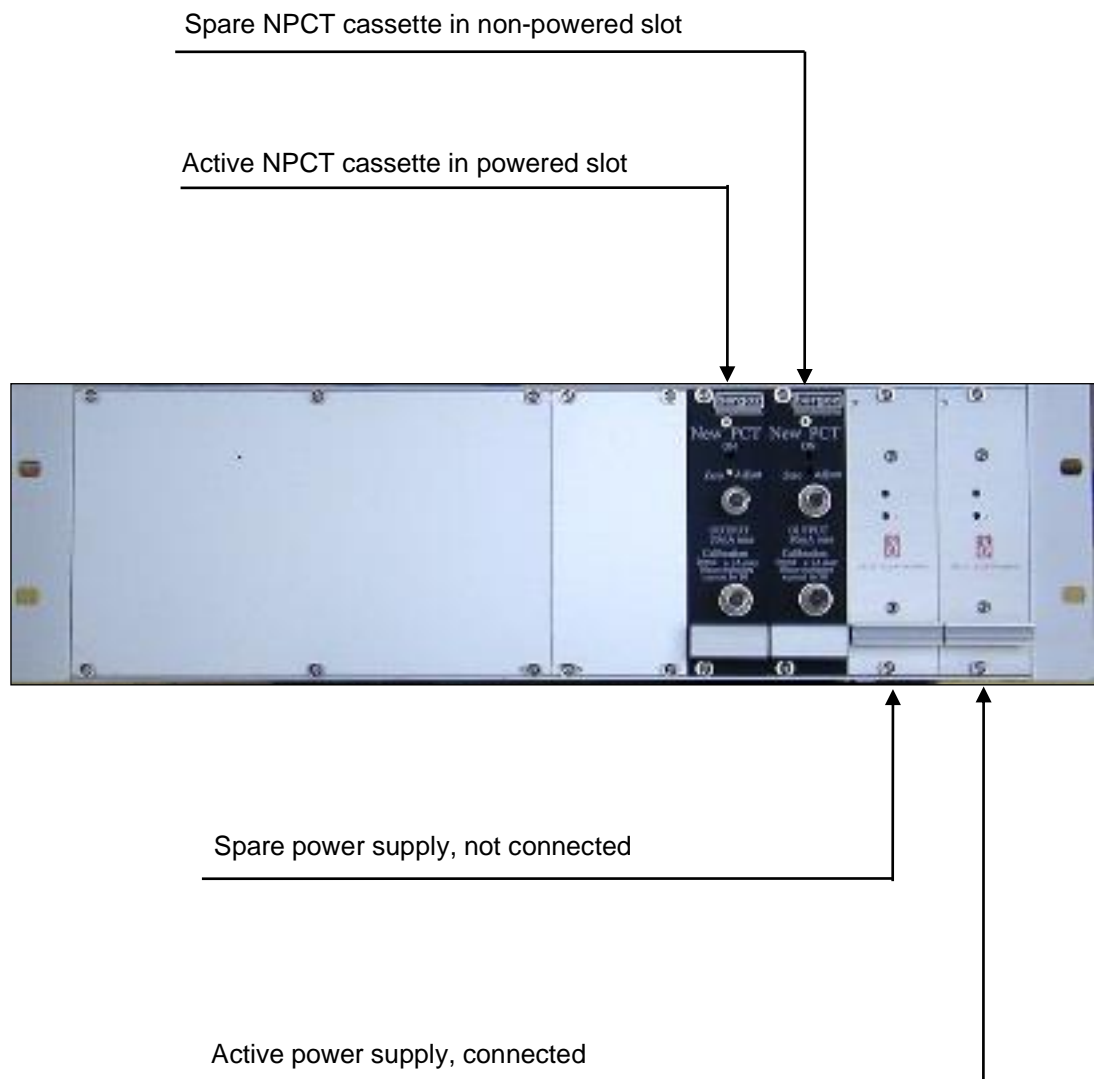
### Rear view



Check the line voltage range marked at the rear of the output chassis. Make sure your mains voltage falls within the range. If it does not, do not connect the NPCT to the mains power supply, but ask for advice from Bergoz Instrumentation or its distributor.

### Active and spare modules

When an NPCT module is damaged –NPCT cassette or power supply– switch off the mains power, remove the damaged unit, then insert the spare unit in the active slot.



## GENERAL DESCRIPTION

The parametric current transformer is designed to measure the DC intensity of a charged particle beam.

It was invented in 1969 at CERN by Klaus B. Unser. It consists of two transformers cascaded in a common feedback loop: a Hereward-type active current transformer and a magnetic parametric amplifier using the second-harmonic detection technique, also called flux gate. It features exceptionally large dynamic range (up to  $2 \times 10^7$ ), high resolution (down to less than  $1 \mu\text{A rms at dc}$ ), excellent linearity and long-term stability.

The magnetic parametric amplifier uses a magnetic modulator of novel design. A digital excitation generator drives its modulator in an avalanche mode with high peak currents. This reduces the effect of Barkhausen noise and improves DC zero stability in a very important way. The demodulator uses a parametric amplifying mechanism with a very good signal to noise ratio. It virtually eliminates the contribution of noise from active amplifier circuits. The Toroid cores of the parametric transformer are made out of high permeability amorphous alloy thin ribbons. We developed a special manufacturing process to improve the magnetic characteristic stability of the parametric current transformer cores. In addition, these cores require a very careful packaging and a sophisticated annealing treatment, both thermal and magnetic, using a longitudinal field and a transverse field. A multilayer magnetic shield using amorphous alloys provides a good shielding factor from external magnetic fields. This is important if low values of current have to be monitored.

NPCT is available in two packaging styles: In-flange models or In-air models.

All NPCT models include:

- 2 x NPCT-E electronics plug-in cassettes (one as spare), and
- 2 x Power supply units (one as spare), plugged in NPCT-RFC 19" x 3U chassis

Note: Every NPCT is delivered with two electronics cassettes NPCT-E. Both cassettes are matched to their associated sensor and cable's length.

When a cassette is used with another unmatched sensor, its output will most likely be unstable and noisy. It may even not work at all. Connecting another sensor does not damage the electronics.

### In-flange models

In-flange models are current transformers whose core(s) are embedded in a pair of flanges. Flanges can be Conflat, ISO, KF, Dependex, EVAC or specials with usual inner diameters. In-flange NPCT are UHV compatible down to  $1\text{e-}9$  mbar. Soap or alcohol cleaning before installation is however recommended; to reach pressure down to  $1\text{e-}11$  mbar, adequate pumping and cleaning, e.g. plasma, are required.

$100^\circ\text{C}$  ( $212^\circ\text{F}$ ) should never be exceeded at any time during bake out or operation. Unlike other Bergoz Instrumentation's In-flange current transformers FCT, ICT, ACCT and CWCT which can – on option – be baked at  $150^\circ\text{C}$  ( $300^\circ\text{F}$ ) or  $185^\circ\text{C}$  ( $365^\circ\text{F}$ ), this is not the case of In-flange NPCT.

In-flange NPCT wall current break ("gap") is a ceramic ring ( $\text{Al}_2\text{O}_3$  99.7%) brazed onto two Kovar transition sleeves.  
Standard models are made from AISI 304 steel, AISI 316LN is available on option.

In-flange models have the below syntax:

In-flange NPCT	
-CFx"-	x" is the CF flanges OD [inch]
-xx.x-	xx.x is the sensor ID [mm]
-xx-	xx is the sensor axial length [mm]
-UHV-	UHV: Sensor UHV compatible with brazed ceramic wall current break; <ul style="list-style-type: none"> <li>- As delivered down to 1e-9 mbar</li> <li>- After adequate cleaning down to 1e-11 mbar</li> </ul>
Example: NPCT-CF6"-96.0-120-UHV	
Options for In-flange NPCT	
-ARBxx-	In-flange NPCT sensor with special arbitrary aperture
-316LN-	In-flange NPCT sensor in AISI316LN instead of 304
-HR-	High-resolution option, noise density < 1 $\mu\text{Arms}/\sqrt{\text{Hz}}$
-VHR-	Very-high resolution option, noise density < 0.5 $\mu\text{Arms}/\sqrt{\text{Hz}}$
-H-	Radiation-tolerant sensor option
-Cxxx-	NPCT sensor cable with PP polypropylene dielectric xxx meters
-RHCxxx-	NPCT sensor cable with Siltem dielectric xxx meters



In-flange NPCT

**In-air models**

In-air models are current transformers whose core(s) are potted in a toroidal casing. In-air NPCT are typically installed over a vacuum chamber whose wall current flow is interrupted by a user-supplied break (“gap”) protected from stress by bellows. The wall current is diverted by a user-supplied wall current bypass. A user-supplied shield prevents the RF leaking out of the gap from radiating over.

In-air NPCT should not be heated above 100°C (212°F) at any time.  
In-air NPCT should not be placed in vacuum, they might burst open, flakes of sodium methyllate may pollute the vacuum.

In-air models have the below syntax:

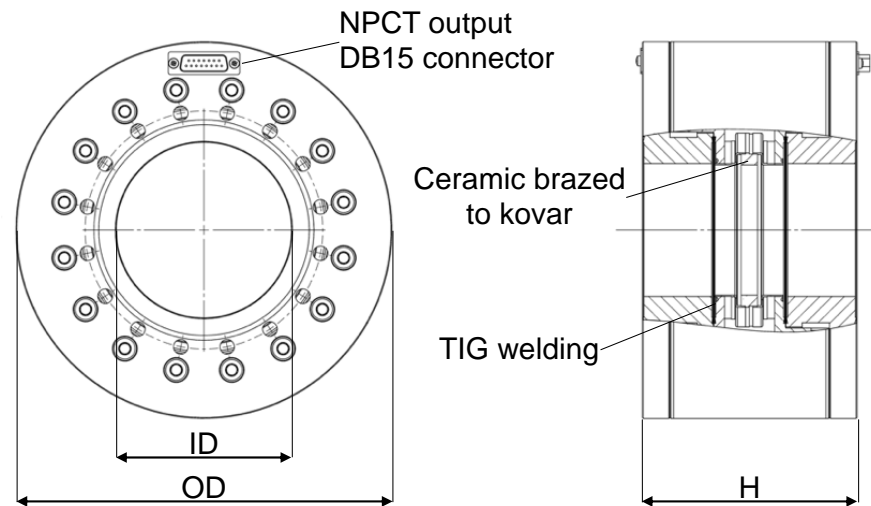
In-air NPCT	
-xxx-	xxx is the sensor ID [mm]
Example: NPCT-130	
Options for In-air NPCT	
-HR-	High-resolution option, noise density < 1 µArms/√(Hz)
-VHR-	Very-high resolution option, noise density < 0.5 µArms/√(Hz)
-H-	Radiation-tolerant sensor option
-Cxxx-	NPCT sensor cable with PP polypropylene dielectric xxx meters
-RHCxxx-	NPCT sensor cable with Siltem dielectric xxx meters



In-air NPCT

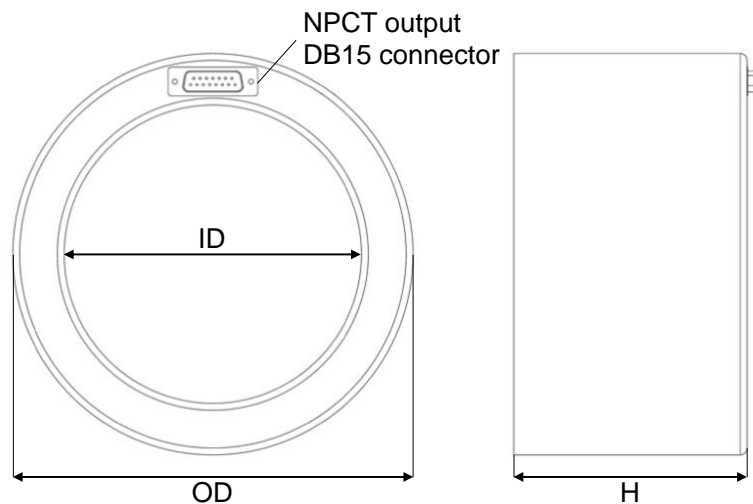
## MECHANICAL DIMENSIONS AND DRAWINGS

### In-flange models



In-flange NPCT sensor order code	Flange OD (inch)	Pipe OD (inch)	NPCT ID (mm)	NPCT H (mm)
NPCT-CF2"1/8-22.2-120-UHV-	2.125"	1"	22.2	120
NPCT-CF2"3/4-34.9-120-UHV-	2.75"	1.5"	34.9	120
NPCT-CF3"3/8-38.0-120-UHV-	3.375"	40 mm	38.0	120
NPCT-CF4"1/2-47.7-120-UHV-	4.5"	2"	47.7	120
NPCT-CF4"1/2-60.4-120-UHV-	4.5"	2.5"	60.4	120
NPCT-CF6"-96.0-120-UHV-	6"	4"	96.0	120
NPCT-CF8"-147.6-120-UHV-	8"	6"	147.6	120
NPCT-CF10"-198.4-120-UHV-	10"	8"	198.4	120

## In-air models



In-air NPCT sensor order code	ID min (mm)	OD max (mm)	H max (mm)
NPCT-055-	55	98	102
NPCT-075-	75	118	102
NPCT-115-	115	158	102
NPCT-130-	130	175	102
NPCT-175-	175	222	102
NPCT-195-	197	250	102
NPCT-202-	202	248	102
NPCT-245-	245	298	102

## Drawings

Drawings in .pdf can be found on our website:

[www.bergoz.com](http://www.bergoz.com) :: Products :: NPCT :: Downloads :: Technical drawings

Dimensions missing on the website can be obtained asking [info@bergoz.com](mailto:info@bergoz.com)

## Electronics chassis

Height: 3U (DIN norms)

Width: 19"

Depth: 300mm + protruding connectors

## SENSOR CONNECTOR

DB15 sensor connector dimensions must be taken into consideration when designing the sensor installation and shield:

### In-flange models

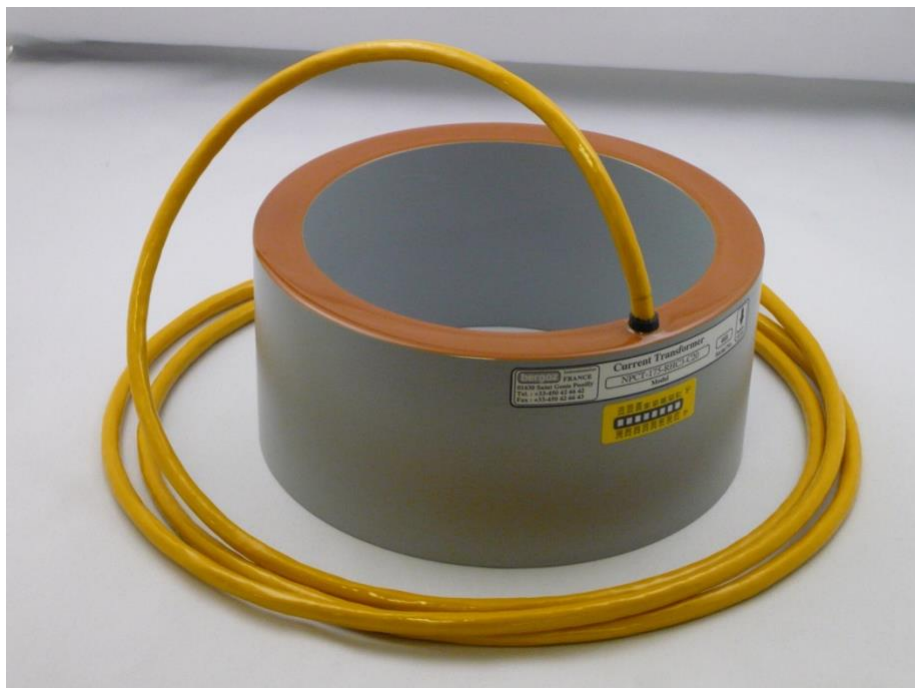
"Standard" sensors which order code does not include "-H" suffix, are equipped with a DB15 male connector affixed to the outer side of the sensor head. The connector dielectric is PTFE. The connector points axially, its base flush with the sensor outer surface.

"Rad-tolerant" sensors, which order code includes "-H" suffix, are equipped with a DB15 male connector affixed to the outer side of the sensor head. The connector dielectric is rad-tolerant glass-fiber-reinforced PBT. The connector points axially, its base flush with the sensor outer surface.

### In-air models

"Standard" sensors which order code does not include "-H" suffix, are equipped with a DB15 male connector affixed to the outer side of the sensor head. The connector dielectric is PTFE. The connector points axially, its base flush with the sensor outer surface.

"Rad-tolerant" sensors, which order code includes "-H" suffix, are equipped with a 3-meter multicore cable going radially out of the toroid sensor head. The cable is rad-tolerant with Siltem dielectric under a polyurethane sheath. The cable is terminated by a DB15 male connector with rad-tolerant dielectric and metallic shells (Farnell 633-859 or 463-024).



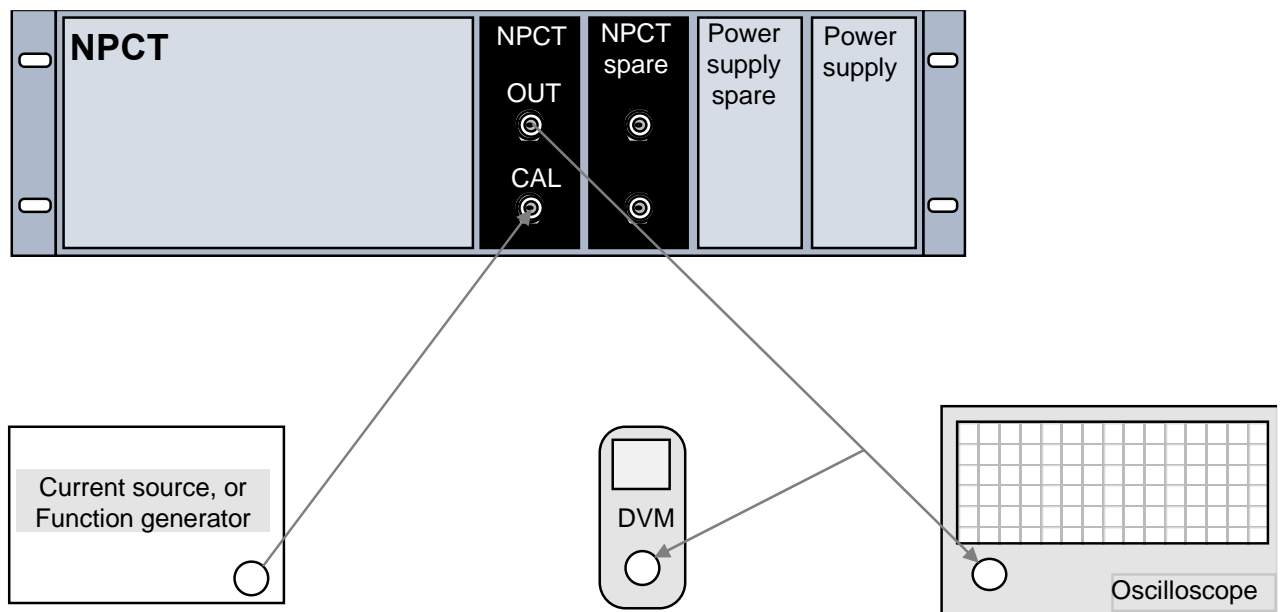
In-air rad-tolerant NPCT with a 3-meter multicore rad-tolerant cable with Siltem dielectric under a polyurethane sheath



## QUICK CHECK

### Checking NPCT operation

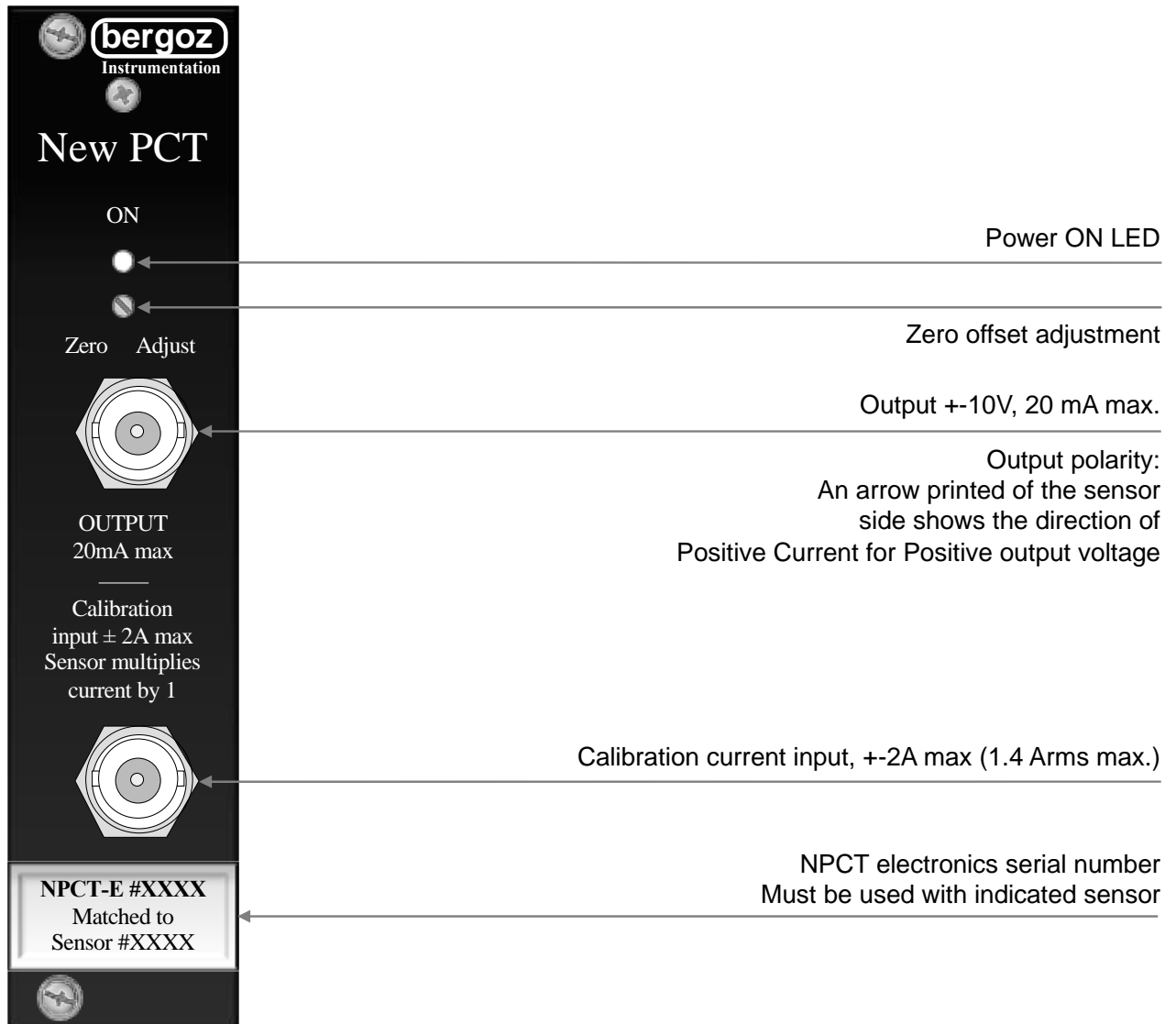
The following steps are intended to make the user familiar with the NPCT operation and behaviour before it is installed in its final place. A DC current source or function generator, and a voltmeter or oscilloscope are the only instruments required for the Quick Check:



Note: Current entered into the calibration input is multiplied by 10 by the 10-turn calibration winding

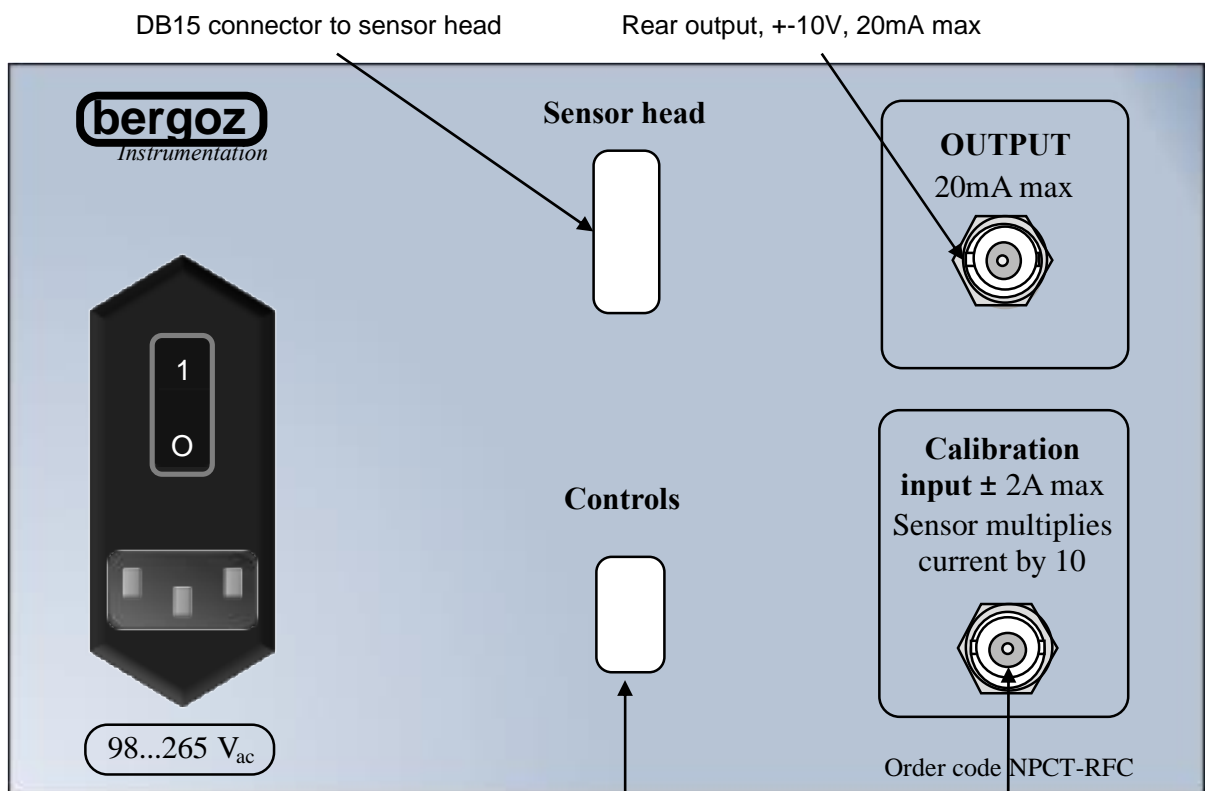
**CONNECT NPCT SENSOR HEAD TO ELECTRONICS BEFORE CONNECTING THE CHASSIS TO THE MAINS**

## NPCT cassette front panel



Note: NPCT is in  $\pm 20A$  range (default range) unless another range is set.  
Ranges can be set through a rear panel DB9 "Controls" connector. See next page.

## NPCT Rear panel and Controls



DB9 Controls connector

Rear panel shown truncated. Real width is 42F

Logic is controlled by TTL levels

Control pins and mnemonics

DB9 pin 2	TEST
DB9 pin 6	RANGE/10
DB9 pin 7	RANGE/100
DB9 pin 5	GRD (Ground)

Control inputs are pulled up (default state = High)

Pull down to ground to set a low state

FULL SCALE RANGES:

Range	Pin 6	Pin 7
$\pm 20A$ (default range)	High	High
$\pm 2A$	Low	High
$\pm 200mA$	High	Low
$\pm 20mA$	Low	Low

TEST

TEST mode when active injects +100mA in the sensor

State Pin 2

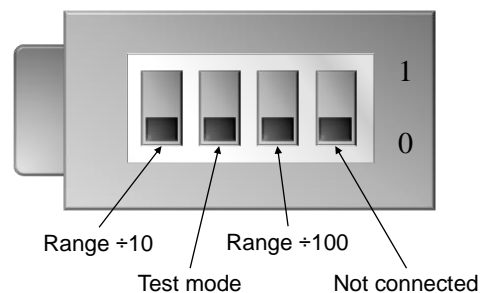
TEST inactive (default state) High

TEST active Low

Note: Ground (GND) is on pin 5

Rear calibration current input  
 $\pm 2A$  max, i.e. 1.4 Arms max.

DB9 Key



When NPCT sensor head is connected to the electronics, connect the chassis to the mains.

Connect a voltmeter, oscilloscope or low-frequency spectrum analyzer to "Output", on the front panel or rear panel.

Then, with a current source or a function generator, enter a signal into the front panel or rear panel "Calibration input".

The current entered into the Calibration input is multiplied by 10, by the 10-turn calibration winding.

Observe the Output signal.

### All ranges check

Increase the NPCT sensitivity. To change the full-scale range, connect rear panel DB9 Control pins 6 and /or 7 to ground.

Note that pins 6 and 7 default state is "High".

Range	Pin 6	Pin 7
±20A (default range)	High (default state)	High (default state)
±2A	Low	High
±200mA	High	Low
±20mA	Low	Low

Note: Ground (GND) is on pin 5.

Preferably, avoid that calibration current exceeds the full-scale range. It may saturate the sensor magnetic cores.

Note: The sensor cannot be damaged by an excessive DC current. Its cores saturate. When the sensor cores are saturated, they will normally desaturate by themselves when the excess current is removed, and NPCT is powered ON. The desaturation process may take many hours, depending on the cores' saturation depth. While the cores desaturate, the NPCT output slowly drifts back to its pre-saturation zero voltage.

### Zero offset check

Turn up and down the front panel Zero Offset multiturn potentiometer and observe the output on a voltmeter. Set the potentiometer so that Output is close to zero.

Note: Setting the range to ±20mA permits a more precise zero setting.

The zero value will change with:

- Temperature of the sensor
- External magnetic field value
- Direction of the magnetic field

Therefore, when the sensor is moved or rotated on its axis, the zero value does change.

Also, the NPCT output dependence on external magnetic field amplitude varies:

There is an angular position of the sensor where the dependence is at its maximum, and  $\pi/2$  further it is at its minimum.

### Functional test

NPCT elementary functions can be tested. To test them, a +100mA test signal can be fed into the sensor head.

The test signal is normally inactive (default state). It can be activated by grounding pin 2 of the DB9 rear panel Controls connector:

TEST	Pin 2
Inactive	High (default state)
Active	Low

Note: Pin 2 default state is "High". Ground (GND) is on pin 5.

## CONTROLS

NPCT is controlled by TTL levels. There are no manual controls (switches). Controls are entered through Rear panel Controls DB9 connector.

Two functions can be controlled:

- Ranges:  $\pm 20A$ ,  $\pm 2A$ ,  $\pm 200mA$  and  $\pm 20mA$ .  
Default range is  $\pm 20A$
- Test: Inactive and Active.  
Active consists of pushing  $+100mA$  current through the sensor head  
Inactive is the default state.

### Ranges

RANGE/10	DB9 Controls pin 6 Default state = High (+5V 4K7 pull-up) Divides full scale range by 10
----------	--

RANGE/100	DB9 Controls pin 7 Default state = High (+5V 4K7 pull-up) Divides full scale range by 100
-----------	---

GND	DB9 Controls pin 5 (ground)
-----	-----------------------------

### Test

TEST	DB9 Controls pin 2 Default state = High (+5V 4K7 pull-up) Activates test, injects $+100mA$ into sensor head
------	---

GND	DB9 Controls pin 5 (ground).
-----	------------------------------

### Range status (optional)

STATUS/10	DB9 Status pin 4
-----------	------------------

STATUS/100	DB9 Status pin 8 DB9 Controls pin 5 (ground)
------------	---

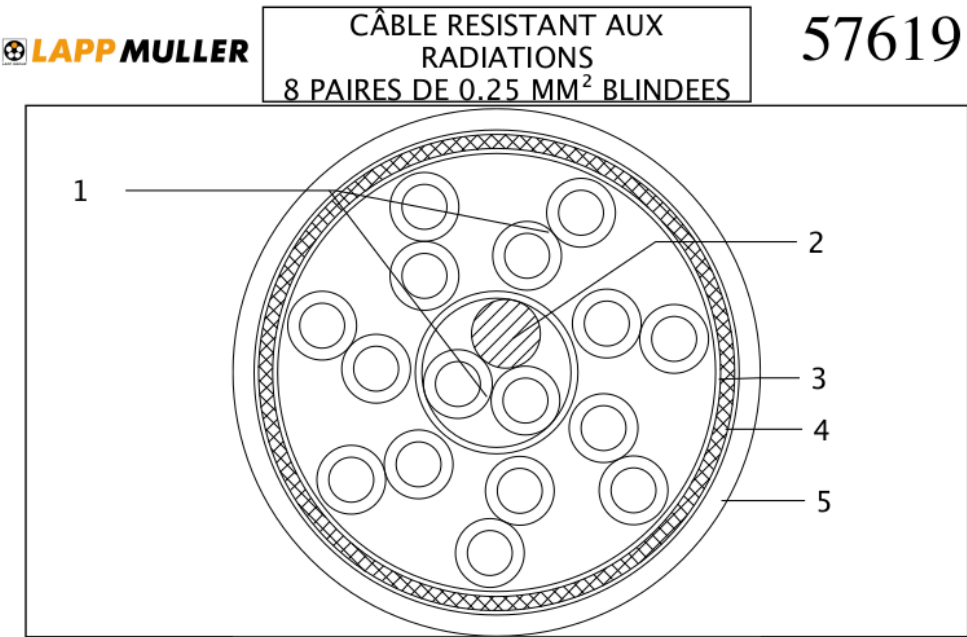
Range <sup>1</sup>	STATUS/10 Pin 4	STATUS/100 Pin 8
$\pm 20A$	High	High
$\pm 2A$	Low	High
$\pm 200mA$	High	Low
$\pm 20mA$	Low	Low
Ground (GND) is on pin 5.		

<sup>1</sup> Some special NPCTs may have other full-scale ranges.  
Refer to this manual's front page for actual full-scale ranges.

INTERCONNECT CABLE AND PAIRS ALLOCATION

Radiation-tolerant cable

NPCT radiation-tolerant cable 5719/A is used to assemble the radiation-tolerant interconnect cable RHCXXX. It is also used on in-air NPCT radiation-tolerant sensor where it is molded in the sensor toroid.



Rep	Désignation des composants	Dia.mm	Caractéristiques
1	16 conducteurs de 0.25 mm <sup>2</sup> en cuivre étamé Isolation SILTEM (Ø élément : 1.1 mm) Assemblage par paire	2.2	<u>Caractéristiques électriques</u>  Tension de service des conducteurs : 0.6/1 KVolts Résistance linéique des conducteurs ≤ 82 Ω/Km
2	Fausse branche	1.1	<u>Caractéristiques générales</u>
3	Ruban terphane d'assemblage	6.1	Tenue au feu : IEC 60332 – 3 Câble sans halogènes
4	Blindage par tresse en cuivre étamé Taux de couverture > 80%	6.8	Tenue aux radiations: 500 Mrads
5	Gaine en SILTEM	8.7	Température de service : – 40°C à +90°C Rayon de courbure statique ≥ 100 mm Rayon de courbure dynamique ≥ 150 mm  Poids : 0.08 Kg/m Diamètre extérieur : 8.7 mm ± 0.4 mm  <u>Repérage des conducteurs :</u>

E								
D								
C								
R	02/02/0	PASSAGE EN GAINÉ SILTEM	Ferre		Rouquet		Besio	

## Standard cable

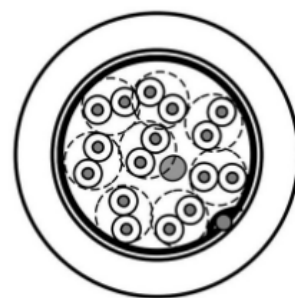
NPCT interconnect cable NPCT-CXXX are assembled using Belden 9508NH multicore cable.

The main characteristics of the Belden 9508NH cable are indicated below. They were extracted from the Belden 9508NH datasheet:

[https://catalog.belden.com/techdata/EN/9508NH\\_techdata.pdf](https://catalog.belden.com/techdata/EN/9508NH_techdata.pdf)

### Product Description:

8-Pair, 24 AWG stranded (7x32) TC conductors, PE insulation, twisted pairs, overall Beldfoil shield (100% coverage), 24 AWG stranded TC drain Wire, LSZH jacket, Flame resistance IEC 60332-3C



### Technical Specifications

Insulation material	PE	
Nom. diameter insulation	1.12	mm
Outer shield material (Beldfoil®)	Bi-Laminate	
Outer shield thickness	9 / 23	µm
Outer jacket material	LSZH-Low Smoke Zero Halogen	
Nom. outer jacket thickness	0.9	mm
Nom. outer jacket diameter	8.4	mm
Nom. conductor DC resistance	78.7	Ohm/km
Nom. outer shield DC resistance	54.1	Ohm/km
Max. capacitance conductor to conductor	98.4	pF/m
Nom. capacitance conductor to other conductor to shield	164	pF/m
Nom. characteristic impedance	75	Ohm
Max. recommended current per conductor	1.1	A
Voltage rating	300	V
Operating temperature range (fixed install)	-45 to +80	°C
Max. pull tension	400	N
Min. bend radius during installation	8'	mm
CPR Euroclass	Dca-s2,d2,a1	
CENELEC Compliance	EN 50290-2-2	
EU RoHS Compliance Date (yyyy-mm-dd)	2005-01-01	
IEC Flammability	IEC 60332-1-2 and IEC 60332-3-2	



## DB15-DB15 interconnect cable pins allocation

Signals	DIN41612D	DB15	Pair	Belden 9508NH
Modulator sense	c1	8	P1	White P1
Modulator sense•	a1	15	P1	Red P1
Excitation•	c2	7	P2	Black P2
Excitation•	a2	14	P2	White P2
Feedback2	c3	6	P3	Black P3
Feedback2•	a3	13	P3	Blue P3
Feedback200	c4	5	P4	Black P4
Feedback200•	a4	12	P4	Green P4
Monitoring	c5	4	P5	Black P5
Monitoring	a5	11	P5	Yellow P5
Calibration•	c6	3	P6	Black P6
Calibration	a6	10	P6	Orange P6
Feedback20/2	c7	2	P7	Black P7
Feedback200/2•	a7	9	P7	Red P7
Ground	c8	1	P8	Black P8
Unused	N/C	N/C	P8	Brown P8

Dots indicate winding polarity.

Excitation wires from winding pairs in phase opposition, thus same polarity.

## SPECIFICATIONS

Full scale ranges	-20 mA...+20 mA -200 mA...+200 mA -2 A... +2 A -20 A... +20 A
Range control	2 TTL lines on rear panel "controls" DB9
Output nominal	-10 V... +10 V, proportional to full scale current
Output over range	up to $\pm 12V$
Noise/resolution (typical)	5 $\mu\text{Arms}/\sqrt{\text{Hz}}$ (higher resolution on option)
Absolute accuracy	$\pm 0.1\%$ $\pm$ zero-offset (can be zeroed) $\pm$ magnetic field drift $\pm$ temperature drift
Linearity error	< 0.1%
Bandwidth (-3dB)	$\pm 20\text{mA}$ range: dc to 8 kHz Other ranges: dc to 10 kHz (dc to 2 kHz flat)
Response time (@ 90%)	< 50 $\mu\text{s}$
Output impedance front panel BNC	100-ohm for high-impedance readout
Output impedance rear panel BNC	100-ohm for high-impedance readout
Output current	20mA max, source or sink
Output connectors	Isolated BNC on rear panel, for readout Isolated BNC on front panel, for monitoring
Readout	High impedance, unipolar or differential
Test function	Injects +100mA in sensor
Test control	TTL line on rear panel "controls" DB9
Calibration function	Under user control
Calibration winding	10-turn floating calibration winding on sensor
Calibration current	from external source (2A max, $Z > 100\text{ ohm}$ )
Calibration connectors	Isolated BNC on rear panel and front panel
Sensor	See dimensions and weight table
Sensor saturation	External magnetic field: 20 Gauss max.
Radiation resistance	Standard sensor contains PVC Optional radiation resistant sensor made from halogen-free high radiation resistance materials (PE, PEEK; Radox.)

Sensor connector	On standard sensor: DB15 male on sensor On radiation-resistant sensor: 3-meter sensor cable, DB15 male terminated, attached to sensor On chassis rear panel: DB15 female
Sensor cable	8-pair multicore DB15/DB15 cable, 8.39-mm outer diameter, 83-mm minimum bending radius, radiation-resistant, flame retardant, low- smoke, halogen-free.
Sensor cable length	130 meters max.
Destructive level	DC current: Unlimited Pulse charge: Unknown, but > 100 mC
Magnetic field sensitivity	100µA/Gauss (1mA/mT), typ.
Saturating field (axial)	100 Gauss (10mT) typ.
Temperature coefficient	Electronics: < 0.1 µA/K Sensor: 5 µA/K typ.
Power supply autorange	98-132 & 185-264 Vac, 50/60 Hz, 1.5 Amax
Mains power connector	IEC; mains power cord not supplied
Operating temperature	-40...+100°C (212°F)
Humidity maximum	Non-condensing
Sensor baking	≤100°C (212°F) max. temperature any time

## MAKING PRECISE MEASUREMENTS WITH NPCT

### The Challenge

NPCT features excellent resolution ( $<0.5 \mu\text{Arms}/\sqrt{\text{Hz}}$ ), outstanding linearity ( $< 0.01\%$  error), over 7 decades. To get the full benefit of these excellent performance, the user must pay special attention to the sensor temperature and its magnetic environment, because:

- Sensor dependence to temperature change is  $5 \mu\text{A} / \text{K}$  typ., up to  $15 \mu\text{A} / \text{K}$  for very large diameters;
- Sensor dependence on external magnetic field change is  $1\mu\text{A}/\mu\text{T}$  typ. ( $=100 \mu\text{A}/\text{Gauss}$ ), up to  $2.5 \mu\text{A}/\mu\text{T}$  for very large diameters.

Note: NPCT-E electronics are fully compensated for temperature change.

To make precise measurements, the NPCT sensor installation is critical.

In-flange NPCT sensors are designed to prevent or damp resonance excited by the beam spectrum.

In-air sensors installation over the vacuum chamber must be such that resonances are prevented.

Users are responsible for resonances occurring in their In-air sensor installation. Installation blueprints can be sent to Bergoz Instrumentation for evaluation prior to installation.

### RF Rejection

The NPCT system is generally protected against RF interference at every stage of the circuit. Cables are susceptible to collect RFI in a high RFI environment, cables could be passed through metallic electrical conduits: Aluminum conduits are appropriate to reject RFI.

### EMI Rejection

EMI couple into electric circuits like NPCT by way of ground loops. Ground loops are intrinsic to electrical installations, they cannot be suppressed, but their interference on instrumentation can be much reduced by common-mode filters. All cable segments must be equipped with common-mode filters.

A cable segment is any cable between two points where the shield is grounded. E.g., a cable between an oscilloscope and a grounded patch panel is a segment. An AC power cord between an instrument and an AC socket is a segment.

Common-mode filters must be effective, i.e., present good mutual inductance coupling, at the interference frequency to be rejected.

MnZn tubes over the cables are effective against high frequencies >500 MHz.  
At low frequency down to 50Hz, iron-based nanocrystalline cores are effective.  
Prefer cores with "soft" B-H loop, e.g., Hitachi Metals Finemet FT-3KL core annealing,  
Vacuumschmelze Vitroperm 500F field-annealed core.

Both ends of every cable segment should be equipped with both types of filters.  
EMI rejection by common-mode filters can exceed -40dB on a methodically executed installation.

Noise conducted by the vacuum chamber surface may cover a wide spectrum from AC 50/60Hz to several MHz; this noise must be treated like EMI-collected noise, by common-mode filters on every cable segment.

### **Grounding scheme**

NPCT system ground reference points depend on the model.

In-flange NPCT ground references are:

- a) The electronics chassis, presumably grounded to the AC mains ground by way of the power cord
- b) The sensor, connected to the vacuum chamber, presumably grounded via the girder

In-air NPCT is grounded through the electronics chassis presumably via the AC mains ground by way of the power cord.

In-air sensor may optionally be grounded to the vacuum chamber by a green/yellow wire sticking out of the sensor.

Grounding the in-air sensor could lower the noise, it depends on the ground loops.

Note: The electronics chassis is grounded through many points, not only via the AC power cord:

- the 19" cabinet ground
- any cable (any!) connected to any chassis in the cabinet.

Any of which may be conductive of a ground loop and cause interference in the NPCT.

NPCT front-panel BNCs and rear chassis BNCs are referenced to the NPCT cassette ground.

They are isolated from the chassis.

## **Output readout**

NPCT output is a high-impedance signal, with output source/sink capability limited to 20mA. Exceeding 20mA (e.g., loading the NPCT output with 50 ohms) may damage the NPCT output buffer.

The type of Readout instrument to be used depends on the user's requirements:

- Oscilloscope
- Voltmeter, 4-1/2 to 7-1/2 digits depending on range and requirements
- System voltmeter, they reject 50Hz/60Hz noise (!)
- 16-bit resolution ADC averaged over many samples to reject noise.

The NPCT output voltage range exceeds -10V...+10V. The Readout instrument input must preferably be bipolar. Even though the beam current is unipolar in most accelerators, the NPCT output may occasionally be of opposite sign due to NPCT zero offset. NPCT output signal must be read by a "Readout instrument".

## **Readout software**

In all cases, the NPCT output must be low-pass filtered down to the frequency range useful to the user.

It can be done by averaging samples, or by a passive RLC low-pass filter.

More than one filter scheme can be applied to respond to users' individual needs.

## **Nulling the NPCT output zero offset**

The zero offset can be nulled with the multi-turn front panel potentiometer. This may not be convenient during normal operations. For optimum precision, the NPCT zero offset should be read in the absence of beam current and deducted from further readings.

In this case, the readout ADC should preferably be bipolar.

## **Readout instrument installation and connection**

The readout instrument must preferably be grounded at the same point as the NPCT chassis. A readout instrument with differential input –i.e. with floating inputs– is advisable when the NPCT and Readout instrument grounds are not the same.

Note: NPCT signal outputs on the front-panel BNC and chassis rear BNC are referenced to the NPCT cassette ground. They are isolated from the chassis.

### **Readout circuit noise rejection**

The readout instrument input should be high-impedance. Therefore, noise can be collected through EMI and RFI may be demodulated by the readout instrument. These interferences can be significantly reduced or eliminated by the use of common-mode filters. Simple common-mode filters can be made by passing the signal cable (twisted pair or coaxial) through a ferrite core. Passing the signal cable several times through the ferrite core increases the magnetic coupling -hence the common-mode noise rejection- by the square of the number of turns... until the capacitive coupling defeats the rejection. In practice, about 7 turns are optimum. The magnetic characteristics of the ferrite cores must correspond to the frequency spectrum of the noise to be rejected.

Ferrite cores can be complemented advantageously by cores of amorphous cobalt alloy or nanocrystalline iron alloy cores next to the ferrite cores.

To reject differential mode noise, install a 100nF ceramic capacitor between signal wire and ground at the input of the readout instrument.

### **Check noise going into the Readout instrument.**

1. Disconnect output cable from NPCT chassis.
2. Short the disconnected BNC connector. Use a BNC 50-ohm termination if no short is available. The noise measured by the Readout instrument is now the noise picked up by the cable.
3. While the BNC is shorted, let the body of the BNC make contact with the NPCT chassis. Now, the Readout instrument measures noise from all sources.

## **IN-FLANGE NPCT INSTALLATION IN THE ACCELERATOR BEAM LINE**

Usual procedures pertinent to the vacuum pressure objective must be applied.  
Install NPCT sensor as far as possible from magnetic stray fields sources.  
Avoid when possible proximity of RF ducts.

In-flange NPCT bolts must be tighten at the recommended torque according to the flange type, but not beyond.

The In-flange NPCT sensor must not be heated beyond its admissible temperature at any time.

Admissible temperature is 100°C (212°F). Above this temperature the sensor alloy annealing is lost and cannot be recovered.

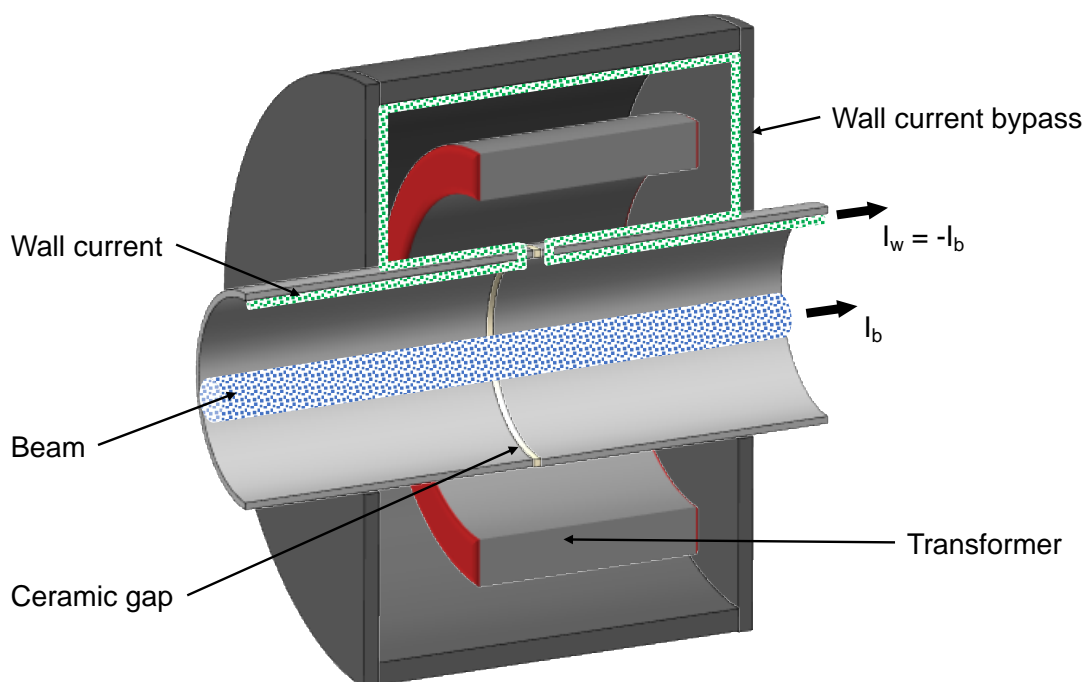
## **INSTALLATION OVER A VACUUM CHAMBER**

The installation of an In-air NPCT on the outside of a vacuum chamber requires some precautions.

- a) The electrical conductivity of the vacuum chamber must be interrupted in the vicinity of the NPCT, otherwise the wall current will flow through the NPCT aperture and cancel the beam current.
- b) The wall current higher frequencies must be diverted around the NPCT through a low impedance path.
- c) A fully-enclosing shield must be installed over the NPCT and vacuum chamber electrical break to avoid RF interference emission.
- d) The enclosing shield forms a cavity. Cavity ringing at any of the beam harmonics must be avoided.
- e) The NPCT must be protected from being heated beyond 100°C (212°F) during vacuum chamber bake-out.
- f) The higher harmonics of the beam should be prevented from escaping the vacuum chamber, because (1) they are not "seen" by the NPCT therefore unnecessary, (2) they heat the NPCT and any other conductive material inside the cavity, (3) they cause various ringing modes in the cavity.

Note: The NPCT must be protected from external magnetic fields. When it is exposed to external magnetic fields it may saturate.





### Wall current break or “gap”

When installing an In-air NPCT over a vacuum chamber, a break or “gap” must be installed in order to stop the wall current.

If vacuum pressure is  $1e-7$  mbar or above, a polymer gasket O-ring can be used between two flanges to assure the desired galvanic isolation.

For vacuum pressures below  $1e-7$  mbar, a ceramic ring brazed to the vacuum chamber is indicated.

### Thermal protection of the In-air NPCT

The NPCT must not be heated beyond  $100^{\circ}\text{C}$  ( $212^{\circ}\text{F}$ ). If the vacuum chamber requires bake out, a thermal shield must be installed between the vacuum chamber (or the heating sleeves) and the NPCT.

The thermal shield can be a simple copper cylinder cooled by water circulating in a copper tube brazed onto the cylinder.

The water circuit must not pass through the NPCT aperture. It must enter and go out on the same side of the NPCT, otherwise it makes a shorting loop around the NPCT toroid.

### **Keeping high harmonics of the beam out of the In-air NPCT cavity**

The transformer, the gap capacitance and the wall current bypass form together a cavity. It is important to prevent unnecessary harmonics from entering the cavity:

The beam current flows through the vacuum chamber.  
The wall current follows the conductive vacuum chamber walls.

The transformer “sees” the wall current  $I_w$ . The higher frequencies of the wall current frequency spectrum will pass through the capacitance of the ceramic gap, while the lower frequencies will enter the cavity and induce a flux in the transformer core.

Note that the full charge of the wall current pulse passes through the cavity, irrespective of the value of the gap capacitance.

## WHAT COULD (AND WOULD) GO WRONG....

### Saturating the Toroid sensor

The magnetic material of the NPCT sensor and high permeability inner shield may be accidentally saturated. When the cores and inner shield have been saturated, the NPCT becomes extremely sensitive to external magnetic fields: its output may remain permanently at saturation levels: beyond +11.5V or -11.5V. The cores and shield may not desaturate spontaneously.

Note: Accidental deep saturation of an NPCT sensor can happen (and has happened) when welding is performed on the vacuum chamber. The current return may pass through the sensor head hole...

Low level saturation is usually nulled by the action of the NPCT modulator. In this case, the NPCT output has a temporary offset up to 100 mV which drifts back to zero after a few hours.

### Demagnetizing the Toroid sensor

Sensor demagnetization is automatic when AC mains is applied to the instrument, provided the saturation is not too deep. In case of deep saturation, contact your distributor or Bergoz Instrumentation for instructions.

### Shorting the Toroid sensor

The NPCT sensor must not be shorted. Any conducting loop passing through the NPCT sensor aperture and closing outside of the sensor is a short. It may be resistive, inductive or capacitive.

Shorting can happen in unexpected ways, when installing additional shields, mechanical holders or braces, thermal shields, water cooling pipes, etc.

A short with an impedance  $< 10 \Omega$  at 30 kHz will cause an output noise increase.

### Unwanted currents

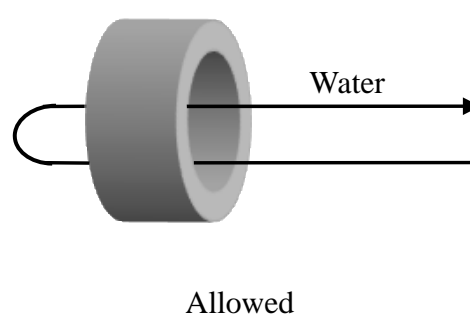
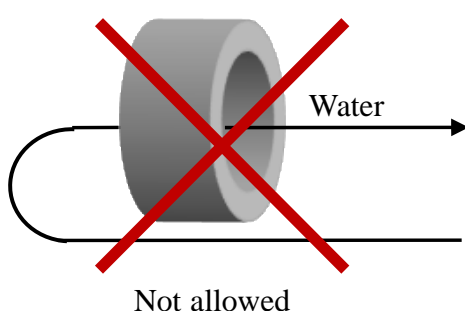
Any current flowing through the vacuum chamber, bake-out sleeve or thermal shield will be "seen" by the NPCT.

All currents entering the NPCT sensor aperture must return to the same side of the NPCT sensor:

E.g., Current to heat bake-out sleeves must return to the same side of the NPCT sensor.

Water cooling pipes passing through the NPCT sensor hole must return and exit on the same side as they entered.

Even a rubber pipe with demineralized water, may carry more than 100  $\mu\text{A}$  of ion current.



### **Ionizing radiations**

The NPCT chassis must not be exposed to ionizing radiations. Doses as small as  $10^2$  Gy may damage the MOS components used.

Yet, NPCT-E electronics does not use high-density digital circuits, thus SEUs are avoided. The NPCT sensor contains materials which can be activated by high energy particles, particularly, the sensor contains large quantities of cobalt and iron.

Other materials used in the construction of the NPCT sensor can be damaged at high doses. Radiation-tolerant NPCT sensors denoted by suffix -H feature tolerance at least one order of magnitude higher than non-H sensors.

## NPCT RADIATION TOLERANCE

NPCTs contain materials which may be damaged by ionizing radiations. They are listed hereafter:

### Organic and radiation-sensitive materials used in the "Standard" sensor<sup>2</sup>:

The "Standard" sensor is supplied when the "Rad-Tolerant" option is not ordered.

Component		Material	Radiation resistance
Wiring insulation		Polyester 1350 tape	10 <sup>6</sup> Gy
		Fiber glass	> 10 <sup>8</sup> Gy
		with rubber adhesive	> 10 <sup>6</sup> Gy
Stress absorbent		Silicon rubber tape SIR	5 x 10 <sup>5</sup> Gy
		Silicon rubber SIR	2 x 10 <sup>5</sup> Gy
Cables	Insulation	Polyvinyl chloride	2 x 10 <sup>5</sup> Gy
	Shield	Aluminium Polyester	> 10 <sup>5</sup> Gy
	Sleeve	Polyvinyl chloride	2 x 10 <sup>5</sup> Gy
Connector	Insulation	PTFE "Teflon"	< 10 <sup>3</sup> Gy

### Organic and radiation-sensitive materials used in the "Rad-Tolerant" sensor<sup>2</sup>:

The "Rad-Tolerant" sensor is supplied when the "Rad-Tolerant" option is ordered. The ordering code and model number are then terminated by -H.

Component		Material	Radiation resistance
Wiring insulation		Polyester 1350 tape	10 <sup>6</sup> Gy
		Fiber glass	> 10 <sup>8</sup> Gy
		with rubber adhesive	> 10 <sup>6</sup> Gy
Stress absorbent		Polyurethane foam PU	5 x 10 <sup>6</sup> Gy
		Polyurethane rubber PUR	5 x 10 <sup>6</sup> Gy
Cables	Insulation	Crosslink Polyolefin	10 <sup>6</sup> Gy
	Static shield	Metallized polyester	> 10 <sup>5</sup> Gy
	Sheath	Polyethylene low-smoke, no-halogen	10 <sup>6</sup> Gy
Connector	In-flange	Glass-fiber-reinforced PBT	10 <sup>6</sup> Gy
	In-air	Connector is on cable: no connector on sensor	

The above radiation resistance values are indicative only. They do not imply any guarantee of whatever nature from the manufacturer.

The manufacturer specifically declines any responsibility for any damage, direct or consequential, caused by ionizing radiations.

<sup>2</sup> Source: Compilation of Radiation Damage Test Data, H.Schönbacher et al.,  
CERN 79-04: <http://cds.cern.ch/record/133188/files/CERN-HS-RP-038-YR-PARTI.pdf?version=1>  
CERN 79-08: <http://cds.cern.ch/record/141784/files/CERN-HS-RP-093.pdf?version=1>  
CERN 82-10: <http://cds.cern.ch/record/141784/files/CERN-HS-RP-093.pdf?version=1>  
CERN 89-12: <http://cds.cern.ch/record/205520/files/CERN-89-12.pdf?version=1>

## **ACKNOWLEDGEMENTS**

The Parametric Current Transformer by Klaus Unser is based on his early DCCT designs for the ISR (CERN) accelerator published in IEEE Transactions on Nuclear Research (1969). Klaus Unser is the inventor of the DCCT. All DC measurement instruments based on 2nd harmonic detection i.e., flux gate, zero-flux, etc. in a common wideband feedback loop are implementations of the fundamental design by Klaus Unser.

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