USER MANUAL

FCT

Fast Current Transformer

Rev. 5.0

www.bergoz.com

bergoz INSTRUMENTATION

More than 40 years of experience recognized in the world of particle accelerators

Record of updates

Version	Date	Updates performed
4.0	01/2018	Review of the full manual. Obsoletes all previous versions
4.1	06/2019	Specifications and dimensions corrections for the FCT with sensitivity 10V/A. Modification of the cover page and creation of the distributors' page.
4.2	04/2021	Modification of saturation specifications Update of the In-air sensor installation drawing Addition of BK200C option, In-flange sensor picture and In-air sensor picture
5.0	07/2024	Manual template update

DISTRIBUTORS

U.S.A.

GMW Associates
www.gmw.com
sales@gmw.com

Japan

Hayashi-Repic Co., Ltd.
www.h-repic.co.jp
sales@h-repic.co.jp

India

GEEBEE International
www.geebeeinternational.com
info@geebeeinternational.com

China

Beijing Conveyi Limited
www.conveyi.com
sales@conveyi.com

South Korea

Seyoung Co., Ltd
www.seyoungsys.com
apark@seyoungsys.com

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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. 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, disassembly, neglect, use of faulty part, accident or abnormal conditions, repair made by the customer, 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: The purchaser/customer must ask for a RMA (Return Material Authorization) number to Bergoz Instrumentation or its local distributor before return of goods. Bergoz Instrumentation will repair or replace any product under warranty at no charge.

For products in need of repair after the warranty period, Bergoz Instrumentation will assess the technical issue and send a quote to the purchaser/customer. The purchaser/customer must provide a purchase order before repairs can be initiated. Bergoz Instrumentation can issue fixed price quotations for most repairs.

RETURN PROCEDURE

All products returned for repair should include a detailed description of the defect or failure as well as name, phone number and email of a contact person to allow further inquiry. Contact Bergoz Instrumentation or your local distributor to determine where to return the product. Returns must be notified by email prior to shipment.

The shipment of a product under warranty or out of warranty back to the factory is paid by the user/customer, including the customs fees. The return of this repaired product under warranty back to the customer is paid by Bergoz Instrumentation.

Return of product out of warranty should be made prepaid or will be invoiced. Bergoz Instrumentation will not accept freight-collect shipments. Shipments should be made via UPS, FedEx or DHL. Within Europe, the transportation services offered by the national Post Offices 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

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 handled.

GENERAL DESCRIPTION

FCT is a passive device. It contains no electronics. FCT is available in two packaging styles: In-flange models or In-air models.

The FCT has a rise time faster than 1ns. Some models have a rise time as low as 175 ps, corresponding to 2 GHz upper frequency cutoff (-3 dB).

The output signal is a current to be measured across a 50Ω user's termination.

The core is a composite of CoFe amorphous alloy and nanocrystalline alloy to optimize the frequency response and minimize ringing. The CoFe alloy is specifically cross-field annealed for this application.

In-flange models

In-flange models are current transformers whose core(s) are embedded in a pair of flanges. Flanges are Conflat with usual inner diameters.

These current transformers are UHV compatible at least to 1e-9 mbar. Soap or alcohol cleaning before installation is however recommended. To reach pressure down to 1e-11 mbar, adequate pumping and prior cleaning, e.g. plasma, are required.

Current transformer temperature should never exceed 100°C (212°F) at any time during bake out or operation unless the current transformer is made from a selection of higher temperature alloys and materials:

- Option BK150C allows bake out at 150°C (300°F)
- Option BK185C allows bake out at 185°C (365°F)
- Option BK200C allows bake out at 200°C (392°F)

Current transformer wall current break (“gap”) is a ceramic ring (Al2O3 99.7%) brazed onto two Kovar transition sleeves.
Standard models are made from AISI 304 steel, AISI 316LN is available on option.

In-flange FCT part numbers follow below syntax:

In-flange FCT	
-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; - As delivered down to 1e-9 mbar - After adequate cleaning down to 1e-11 mbar
-xx.x	xx.x is the sensitivity of the sensor [V/A]
Example: FCT-CF6”-60.4-40-UHV-5.0	
Options for In-flange FCT	
-ARBxx-	In-flange FCT sensor with special arbitrary aperture
-316LN-	In-flange FCT sensor in AISI316LN instead of 304
-BK150C-	In-flange FCT sensor bakeable at 150°C (300°F)
-BK185C-	In-flange FCT sensor bakeable at 185°C (365°F)
-BK200C-	In-flange FCT sensor bakeable at 200°C (392°F)
-LD-	Low Droop sensor option
-H	Radiation-tolerant sensor option, all components R.I.>6

In-air models

In-air models are current transformers whose cores are potted in a toroidal copper casing.

In-air FCTs are typically installed over a vacuum chamber whose wall current flow is interrupted by a user-installed break (“gap”) protected from stress by bellows. The wall current is diverted by a user-installed wall current bypass. A user-installed shield prevents RF fields radiating out of the gap.

In-air FCT should not be heated above 100°C (212°F) at any time.
In-air FCT should not be placed in vacuum, they might burst.
Specially degassed In-air ICT can be placed in low vacuum (1e-4 mbar).

In-air ICT part numbers follow below syntax:

In-air FCT	
-xxx-	xxx is the sensor ID [mm]
-xx.x	xx.x is the sensitivity of the sensor [V/A]
Example: FCT-055-5.0	
Options for In-air FCT	
-VAC-	In-air FCT sensor degassed
-LD-	Low Droop sensor option
-H	Radiation-tolerant sensor option, all components R.I.>6

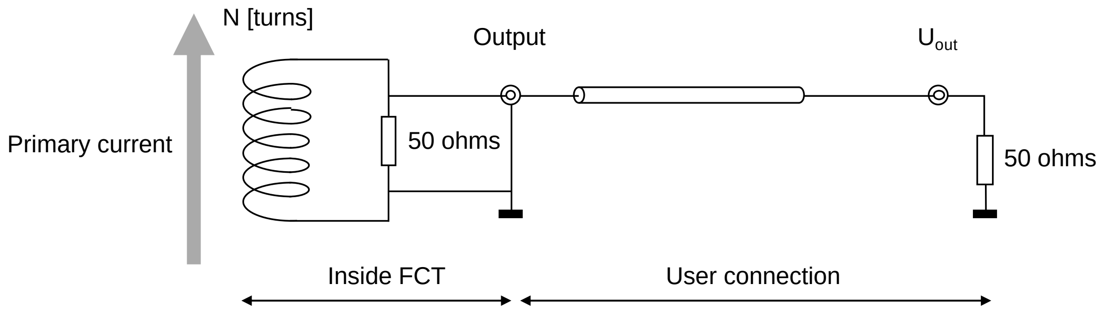
FCT main advantages

- The FCT displays the beam current with a minimum of distortion up to very high frequency. It is therefore, primarily, an instrument to be used with an oscilloscope.
- Very low ringing when it is properly installed (See: "Installation on the vacuum chamber" in this manual).

FCT limitations

- The FCT, like all transformers, differentiates the signal. When the observed pulses are longer than a few microseconds, the output droop of the FCT becomes excessive.
- The FCT has eddy current loss up to a few percent. Eddy current losses are frequency dependent, increase towards the higher frequencies. Yet, the FCT is still the best instrument to visualize a short, fast pulse on an oscilloscope when non-contact measurement is a necessity: particle beams, high voltage, etc.

OPERATING PRINCIPLE



FCT CHARACTERISTICS

FCT bandwidth is limited by a lower and an upper cutoff frequency.

Lower cutoff frequency

The droop is equal to

$$D = 2\pi f_{low}$$

Where
D [1/s] is the droop
f_{low} [Hz] is the lower cutoff frequency (-3dB)

The droop is also equal to

$$D = \frac{1}{\tau}$$

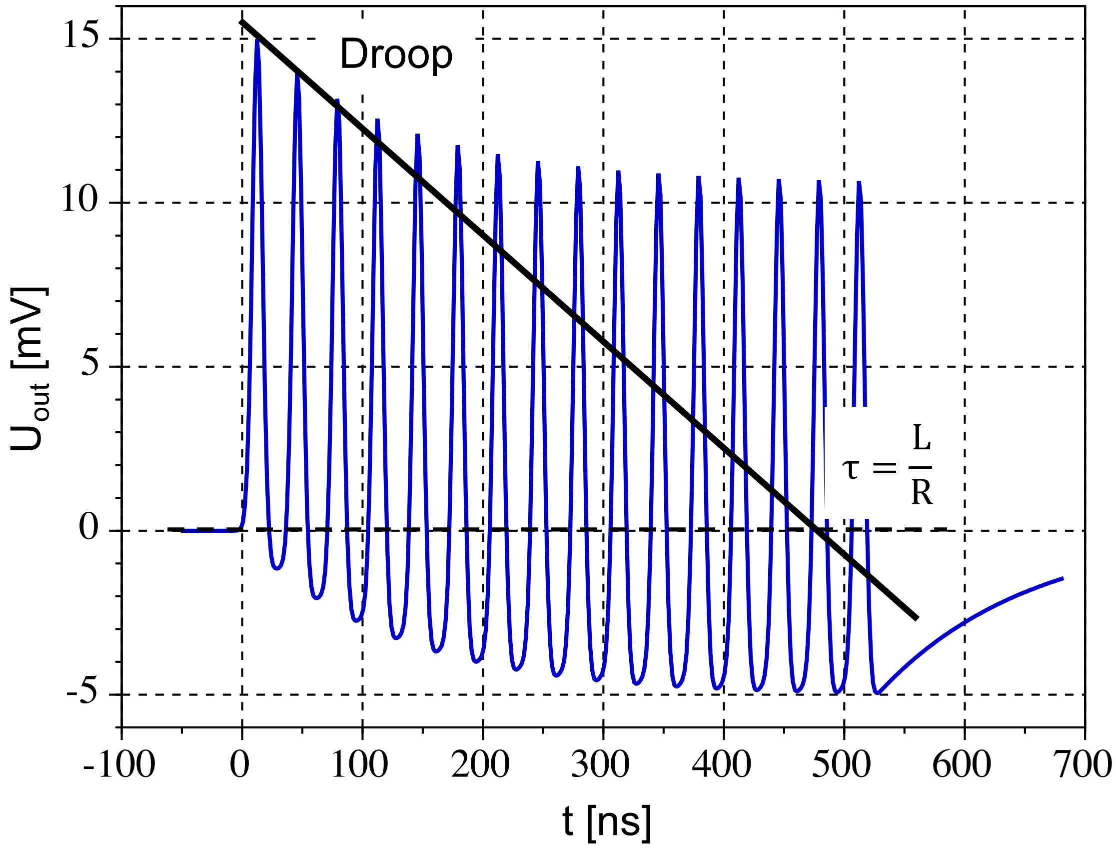
Where
τ [s] is the differentiating time constant

The differentiating time constant is equal to

$$\tau = \frac{L}{R}$$

Where
L [H] is the core winding inductance
R [ohm] is the load seen by the winding, i.e., the combination of the FCT internal load in parallel with the user's termination.

Example of FCT output signal droop:
Observe on the plot below the effect of a transformer's lower cutoff frequency, i.e., its droop



Upper cutoff frequency

The upper cutoff frequency (-3dB) is the consequence of a complex combination of elements:

a) The eddy currents developing inside the core.

b) The parasitic capacitance of the core windings, e.g., the capacitance between adjacent turns, between turn and core, between winding and outer shell.

c) The winding wire inductance.

Finally, the necessary adaptation between the core winding source impedance, the 50 ohm connector and the cable further limit the bandwidth.

SPECIFICATIONS

Standard models

Standard models feature the widest bandwidth.

Sensitivity (nominal)	0.25	0.5	1.25	2.5	5.0	V/A
Turns ratio (old reference)	100:1	50:1	20:1	10:1	05:1	
Rise time (typ.)	0.60	0.30	0.23	0.30	0.39	ns
Droop	< 1	< 3	< 6	< 10	< 32	%/µs
Upper cutoff frequency -3dB typ.*	0.58	1.17	1.50	1.17	0.90	GHz
Lower cutoff frequency -3dB typ.*	< 1.6	< 5	< 9.5	< 16	< 50	kHz
L/R time constant (min.)	100	35	17	10	5	µs
Max. charge/pulse	8100	2000	324	81	20	µC
Max. rms current (f >10kHz)	2.7	2.7	2.7	2.7	2.7	A
Max. peak current (pulses = 1ns)	2	0.4	0.2	0.1	0.1	kA

* Depends on FCT sensor dimensions and selected options

Please contact Bergoz Instrumentation for 10.0 V/A sensitivity specifications.

Low droop (-LD) models

Sensitivity (nominal)	0.25	0.5	1.25	2.5	5.0	V/A
Turns ratio	100:1	50:1	20:1	10:1	05:1	
Rise time (typ.)	1	0.54	0.40	0.50	0.78	ns
Droop	< 0.05	< 0.2	< 1	< 3	< 8	%/µs
Upper cutoff frequency -3dB typ.*	350	650	850	700	450	MHz
Lower cutoff frequency -3dB typ.*	< 0.08	< 0.32	< 1.6	< 5	< 13	kHz
L/R time constant (min.)	2000	500	100	35	12	µs
Max. charge/pulse	8100	2000	324	81	20	µC
Max. rms current (f >10kHz)	2.7	2.7	2.7	2.7	2.7	kA
Max. peak current (pulses = 1ns)	2	0.4	0.2	0.1	0.1	A

* Depends on FCT sensor dimensions and selected options

Please contact Bergoz Instrumentation for 10.0 V/A sensitivity specifications.

ELECTRICAL CONNECTIONS

In-flange and In-air ICTs are equipped with SMA jack connectors with PTFE dielectric.

FCTs ordered with radiation tolerant option -H are equipped with SMA jack connectors with PEEK dielectric.

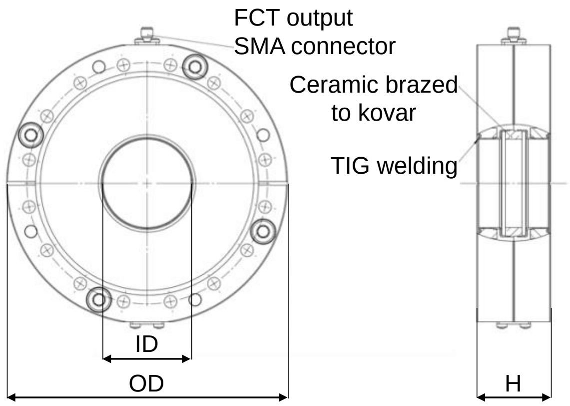
BNC or N-type connectors are available on request.

OUTPUT SIGNAL POLARITY

The Fast Current Transformer is bipolar.
Arrows are printed on the outer surface of the toroid. Charges (positive) crossing the aperture in the direction of the arrow give positive outputs. For example, an electron beam (= negative charge) passing in the direction of the arrow yields a negative output.

MECHANICAL DIMENSIONS AND DRAWINGS

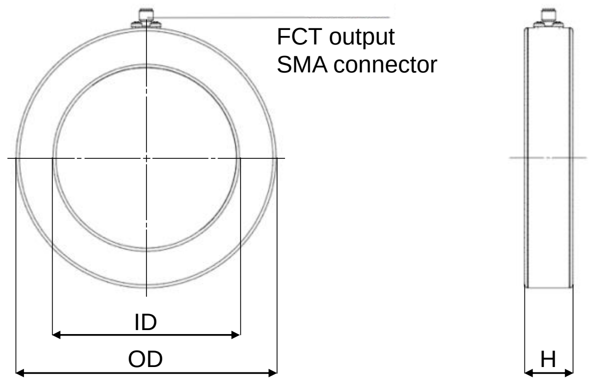
In-flange models



In-flange FCT sensor order code	Flange OD (inch)	Pipe OD (inch)	Mating flange	FCT ID (mm)	FCT H (mm)
FCT-CF3"3/8-22.2-40-UHV-xx	3.375”	1"	DN/NW50CF	22.2	↓
FCT-CF4"1/2-34.9-40-UHV-xx	4.5”	1.5"	DN/NW63CF	34.9	
FCT-CF4"1/2-38.0-40-UHV-xx	4.5”	40 mm	DN/NW63CF	38.0	
FCT-CF6"-47.7-40-UHV-xx	6”	2"	DN/NW100CF	47.7	
FCT-CF6"-60.4-40-UHV-xx	6”	2.5"	DN/NW100CF	60.4	
FCT-CF6"3/4-96.0-40-UHV-xx	6.75”	4"	DN/NW130CF	96.0	
or FCT-CF8"-96.0-40-UHV-xx	8”	4"	DN160/NW150CF	96.0	
FCT-CF10"-147.6-40-UHV-xx	10”	6"	DN/NW200CF	147.6	
FCT-CF12"-198.4-40-UHV-xx	12”	8"	DN/NW250CF	198.4	
FCT-CFXX"-XXX-XX-UHV-5.0 V/A and lower					40.0

Please ask Bergoz Instrumentation for FCT-CFXX"-XXX-XX-UHV-10.0 V/A dimensions.

In-air models



In-air FCT sensor order code	ID min (mm)	OD max (mm)	H max (mm)
FCT-016-xx	16	42	
FCT-028-xx	28	64	
FCT-055-xx	55	91	
FCT-082-xx	82	118	
FCT-122-xx	122	156	
FCT-178-xx	178	226	
FCT-XXX-2.5 V/A and lower			22
FCT-XXX-5.0 V/A			35

Please ask Bergoz Instrumentation for FCT-XXX-10.0 V/A dimensions.

Drawings

Drawings in .pdf can be found on our website:
www.bergoz.com :: FCT :: Downloads :: Technical drawings
Dimensions missing on the website can be obtained asking info@bergoz.com

INSTALLATION

In-flange models

In-flange model mechanical parts are in direct electrical contact with the vacuum chamber. Its output connector body and, hence, the coaxial cable shield are also in direct electrical contact with the vacuum chamber. It is therefore important to equip every segment of the coaxial cable with common mode filters to mitigate ground loops. A cable segment is any section of cable between two grounded connectors or bulkheads, for example through a grounded patch panel.

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

In-air models

In-air FCT must be installed over the vacuum chamber, not too far away from the wall current gap. It is recommended to install bellows to avoid stress on the gap, wall current bypass and RF overall shield.

The output connector body is in direct electrical contact with the In-air FCT copper shell. Therefore, to prevent ground loops, it is recommended that the In-air FCT shell is electrically isolated from the vacuum chamber.

Common mode filters

To improve EMI rejection common mode filters should be installed at both ends of each cable segment. Each filter shall comprise a MnZn ferrite core for high frequency >500 MHz rejection, and an iron-based nanocrystalline core with soft B-H loop for low frequency rejection.

INSTALLATION OVER A VACUUM CHAMBER

The installation of an In-air FCT 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 ICT, otherwise beam and beam-induced wall current will flow through the FCT aperture and cancel each other. This vacuum chamber electrical break should be designed to be high impedance over the entire FCT bandwidth, but low impedance at higher frequencies. The higher harmonics of the beam induced fields should be prevented from escaping the vacuum chamber, because:
    a. they are not "seen" by the FCT therefore unnecessary
    b. they heat the ICT and any other conductive materials inside wall current bypass and RF shield
    c. they cause various ringing modes inside wall current bypass and RF shield.

b) Wall current DC and very low frequency components must be diverted around the FCT through a low impedance path.

c) A fully enclosing RF shield must be installed over wall current bypass, FCT and vacuum chamber electrical break to avoid emission of RF radiation.

d) The enclosing shield forms a cavity. Cavity ringing at any of the beam harmonics must be avoided.

e) The ICT must be protected from being heated beyond 100°C (212°F) during vacuum chamber bake-out.

Wall current break or "gap"

When installing an In-air FCT over a vacuum chamber, an electrical break or "gap" must be installed in order to stop the wall current induced by the beam.

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

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

Thermal protection of the In-air FCT

The FCT must not be heated beyond 100°C (212°F). If the vacuum chamber requires bake out, a thermal shield must be installed between the vacuum chamber (or the heating sleeves) and the ICT.

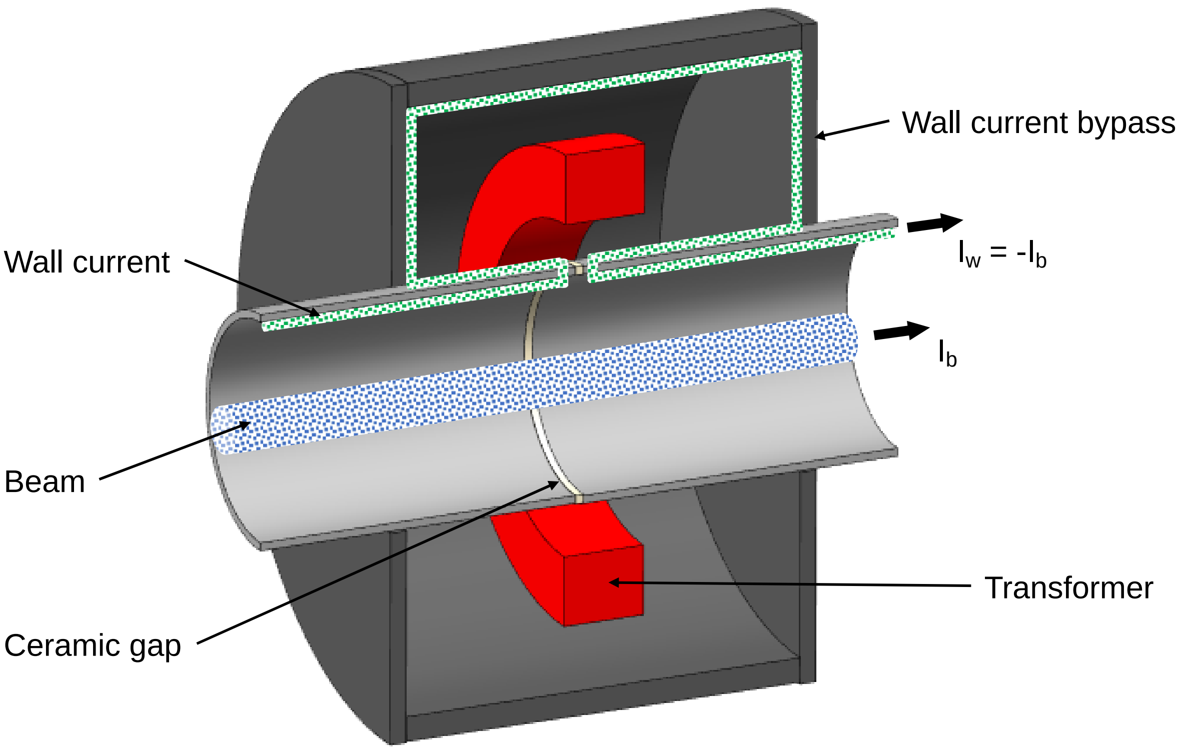
The thermal shield can be a simple copper cylinder cooled by water circulating in a copper tube brazed onto the cylinder.

The water circuit must not pass through the FCT aperture. It must enter and leave on the same side of the FCT, otherwise it may create an electrical short around the FCT toroid.

Keeping high harmonics of the beam out of the In-air FCT cavity

Wall current break, wall current bypass and RF shield form a cavity. The FCT is placed inside this cavity.

The beam current flows through the vacuum chamber. Its electromagnetic fields induce a wall current in the conductive vacuum chamber walls. The flow of this wall current is interrupted by the wall current break. Depending on gap capacitance, high frequency components see a low impendence and continue to flow over the gap. DC and lower frequency components see a high impedance and are diverted over the wall current bypass. Depending on cavity geometry also some high frequency resonances may be present inside the cavity.



The transformer “sees” all currents passing through its aperture, i.e. beam current I_b and high frequency components of wall current I_w. Since these two currents cancel each other, only the beam current components whose corresponding wall current is diverted over the wall current bypass and the high frequency resonances are visible to the transformer. Only these currents induce a magnetic flux in its core.

By increasing the gap capacitance all unnecessary frequencies can be kept out the cavity. By reducing the size of the cavity high frequency resonances can be avoided.

Note that always the full charge of the beam current pulse is visible to the transformer, irrespective of the value of the gap capacitance.

FCT RADIATION RESISTANCE

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

Organic and radiation-sensitive materials used in the "Standard" sensor[1]:

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

Component	*Material*	*Radiation resistance*
Wiring insulation	Polyester 1350 tape	10^6 Gy
	Fiber glass	> 10^8 Gy
	with rubber adhesive	> 10^6 Gy
Stress absorbent	Silicon rubber tape SIR	5 x 10^5 Gy
	Silicon rubber SIR	2 x 10^5 Gy
Connector dielectric	PTFE "Teflon"	< 10^3 Gy

Organic and radiation-sensitive materials used in the "Rad-Hard" sensor[1]:

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	10^6 Gy
	Fiber glass	> 10^8 Gy
	with rubber adhesive	> 10^6 Gy
Stress absorbent	Polyurethane foam PU	5 x 10^6 Gy
	Polyurethane rubber PUR	5 x 10^6 Gy
Connector dielectric	Poly-ether-ether-ketone PEEK	6 x 10^7 Gy

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.

[1] *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

ACKNOWLEDGEMENT

FCT was developed at CERN during the 80’s by Dipl. Ing. Klaus B. Unser to monitor the LEP beam.

FCT remains the fastest (widest bandwidth) transformer with linear output to measure particle beams.

Last revised: Saint-Genis-Pouilly, July 2024