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Fast Current Transformer

User's Manual

Rev. 4.2

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

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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 fax 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

The instrument designated as "Fast Current Transformer" may become RADIOACTIVE when exposed to ionizing radiations.

Standard models contain:

- Cobalt Up to 0.4 Kg
- Iron..... Up to 0.2 Kg

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 can be Conflat, ISO, KF, Dependex, EVAC or specials with usual inner diameters.



In-flange FCT are UHV compatible down to 1e-9 mbar. Soap or alcohol cleaning before installation is however recommended; to reach pressure down to 1e-11 mbar, adequate pumping and cleaning, e.g. plasma, are required.

100°C (212°F) should never be exceeded at any time during bake out or operation unless it 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)

In-flange FCT 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 models have the 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)
-SH2L-	2-layer magnetic shield with limited bandwidth
-SH4L-	4-layer magnetic shield with limited bandwidth
-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 core(s) are potted in a copper toroidal casing.



In-air FCT 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 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 open.
 Specially degassed In-air FCT can be placed in mild vacuum (1e-4 mbar).

In-air models have the 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
-SH2L-	2-layer magnetic shield with limited bandwidth
-SH4L-	4-layer magnetic shield with limited bandwidth
-LD-	Low Droop sensor option
-H	Radiation-tolerant sensor option, all components R.I.>6

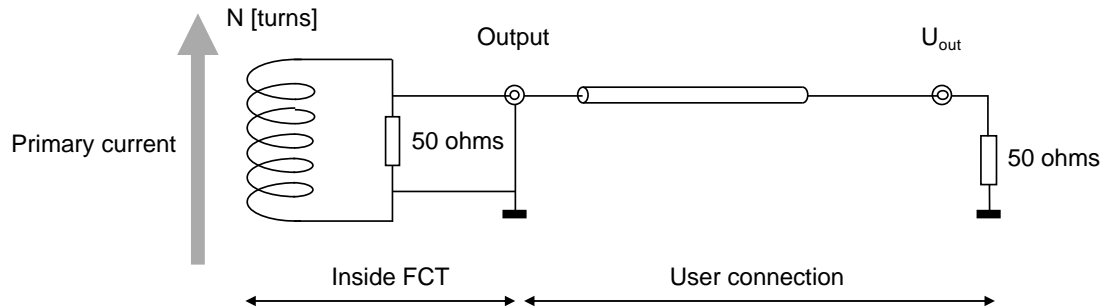
FCT main advantages

- 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

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

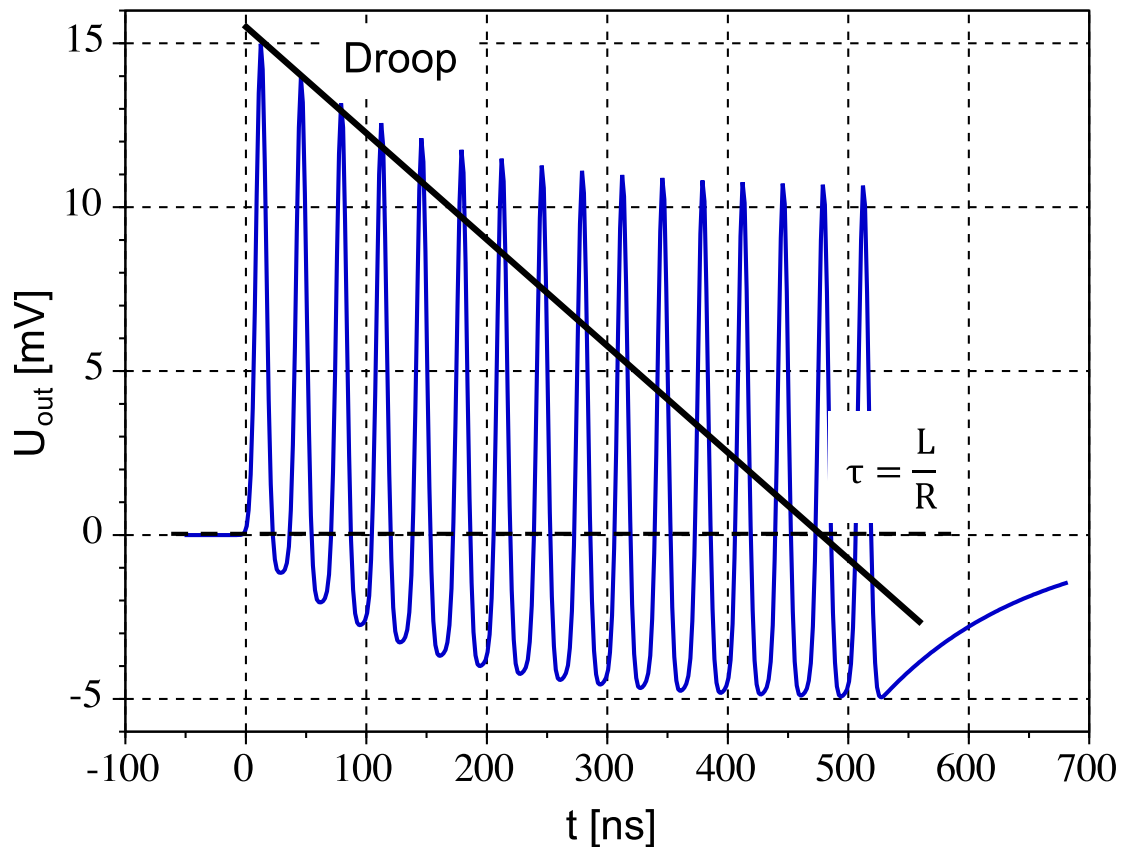
Where

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:

- The eddy currents developing inside the core.
- The parasitic capacitance of the core windings, e.g., the capacitance between adjacent turns, between turn and core, between winding and outer shell.
- 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.
 Technology: Predominantly amorphous

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.)	0.6	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	1.5	1.17	0.9	GHz
Lower cutoff frequency -3dB	<1.6	<4.8	<9.5	<16	<32	kHz
L/R time constant (min.)	100	35	1.75	10	5	μs
Max. charge/pulse	4050	1050	160	40	10	μC
Max. rms current (f >10kHz)	2.7	2.7	2.7	2.7	2.7	A
Max. peak current (pulses = 1ns)	3780	980	150	38	9.5	kA

Please ask Bergoz Instrumentation if specifications are needed for the FCT with sensitivity 10V/A.

Low droop (-LD) models

Technology: Predominantly nanocrystalline

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	<0.08	<0.32	<1.6	<5	<13	kHz
L/R time constant (min.)	2000	500	100	30	12	μs
Max. charge/pulse	4050	1050	160	40	10	μC
Max. rms current (f >10kHz)	2.7	2.7	2.7	2.7	2.7	kA
Max. peak current (pulses = 1ns)	3780	980	150	38	9.5	A

Please ask Bergoz Instrumentation if specifications are needed for the FCT with sensitivity 10V/A.

ELECTRICAL CONNECTIONS

Coaxial connectors on the FCT sensor

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

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

BNC or N-type connectors are available on request.

OUTPUT SIGNAL POLARITY

The Fast Current Transformer is bipolar.

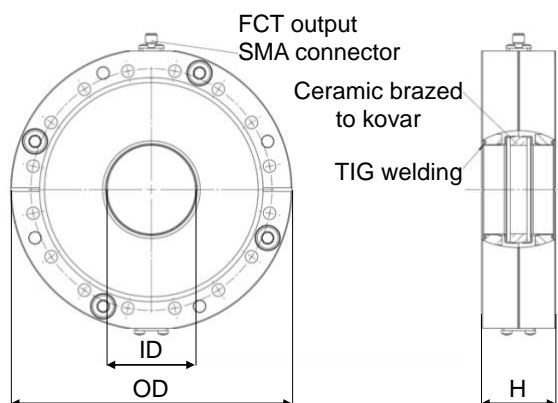
Arrows are printed on the outer surface of the toroid.

Charges (positive) crossing the aperture in the direction of the arrow give positive outputs.

E.g. an electron beam passing in the direction of the arrow yields a negative output.

MECHANICAL DIMENSIONS AND DRAWINGS

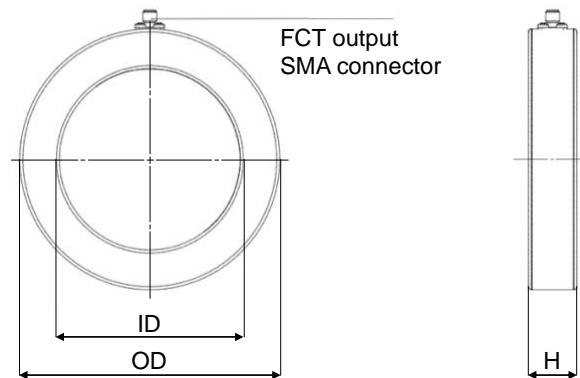
In-flange models



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 or FCT-CF8"-96.0-40-UHV-xx	6.75" 8"	4"	DN/NW130CF 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 FCT mechanical parts are in direct electrical contact with the vacuum chamber. Its output connector body, hence, the cable shield is also in direct electrical contact. It is therefore of paramount importance to equip every section of the coaxial cable with common mode filters to mitigate ground loops. A cable section is any length of cable which connector body is grounded at both ends, e.g., through a 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 to prevent RF leaking outside are recommended.

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

Common mode filters must be installed at both ends of each cable segments. Each filter must comprise one MnZn ferrite tube, core or bead, and one iron-based nanocrystalline core, e.g., Hitachi Metals' Finemet alloy FT-3KL.

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 FCT, otherwise the wall current will flow thru the FCT aperture and cancel the beam current.
- b) The wall current higher frequencies must be diverted around the FCT thru a low impedance path.
- c) A fully-enclosing shield must be installed over the FCT 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 FCT 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 FCT therefore unnecessary, (2) they heat the FCT and any other conductive material inside the cavity, (3) they cause various ringing modes in the cavity.

Note: The FCT does not need to be protected from external magnetic fields. When it is exposed to external magnetic fields it may saturate; this causes the droop to increase up to a factor of 2. It has no effect on the FCT linearity.

Wall current break or “gap”

When installing an In-air FCT 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 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 FCT.

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

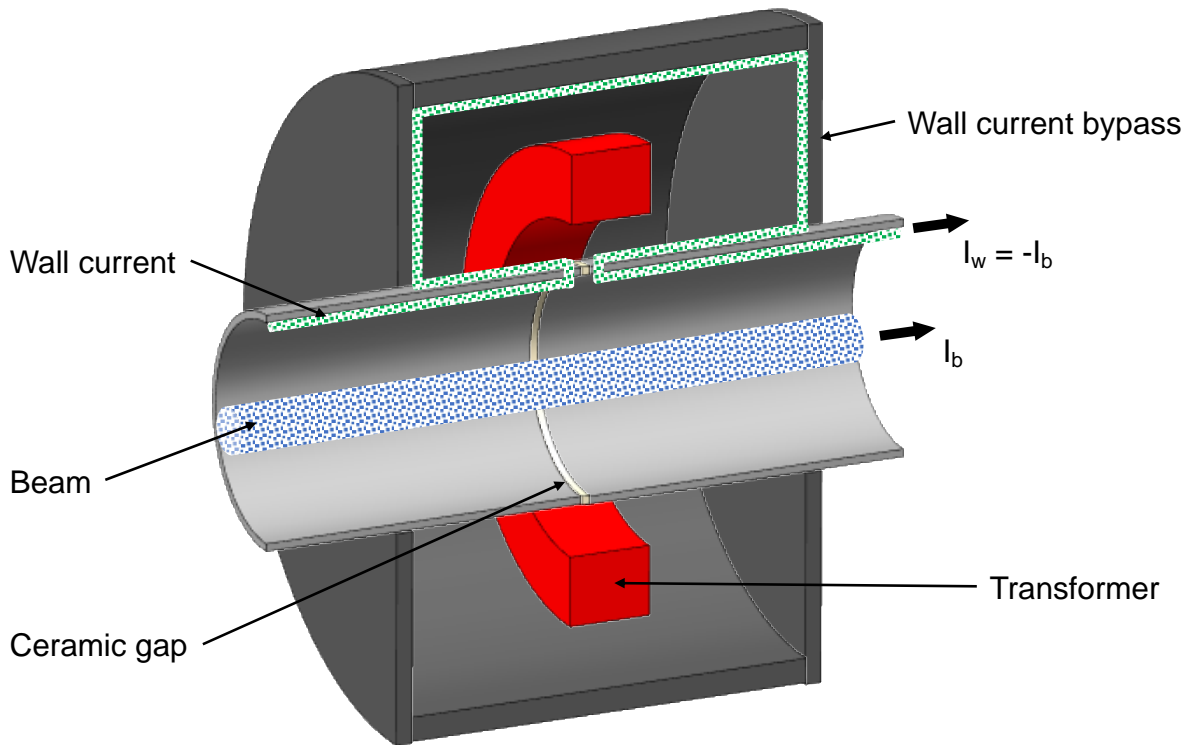
The water circuit must not pass thru the FCT aperture. It must enter and go out on the same side of the FCT, otherwise it makes a shorting loop around the FCT toroid.

Keeping high harmonics of the beam out of the In-air FCT 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 thru 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 thru 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 thru the cavity, 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" sensor¹:

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" sensor¹:

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-PART1.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.

Saint Genis Pouilly

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