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Technical Specifications (In-Cash Procurement)

Summary of PPMI accelerometer specification

The purpose of this contract is to increase the integrity limits of COTS accelerometers for their use at the Port Plugs of the ITER tokamak in order to comply with its harsh operating conditions. The Contractor will improve the thermal and radiation resistance specifications of a market-available (or already developed, stored on his premises, etc.) fibre-optic accelerometer which already meets the measurement requirements specified in section 3. The purpose is to provide a set of sensors, ...

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1 Purpose

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The accelerometers in ITER Port Plugs shall operate many years without service at rather harsh EM, radiation, thermal and vacuum environment: Accordingly, they should be EMI-insensitive, robust, employ only rad-hard, high temperature and vacuum compatible materials, well cooled by thermal conduction to diffuse away the nuclear heat, preferably without kinematic and sliding joints, etc.

2 Scope

The scope of this contract covers the adaptation, test, supply and qualification for the following elements with different requirements on measurement ranges and accordingly different sensitivities:

- Optical sensors to measure equatorial port plugs accelerations
- Optical sensors to measure upper port plugs accelerations

Integration of the sensors will also be considered in terms of restricted exterior dimensions, layout of connections, attachment scheme, and signal transmission to the interrogator hardware. For the latter, specific activities will be performed for evaluating the fibre loop connection as well as specifications and procedures for detecting and resolving sensor or line one-point failures.

2.1 Scope of the work

Although none of the items in the scope of this contract have investment protection and safety important functions, the contractor shall ensure that all procedures and requirements defined in [A1] and [A2] are propagated by its staff at all level throughout the implementation of this project. This shall particularly relate to the propagation of requirements related to the maximum impurity level of raw materials (see section 6.1.4) and traceability of all hardware from material supply to delivery and through qualification.

The work delivered by the contractor is covered by the following steps:

1. Prepare a project detailed schedule and a QA plan to be agreed during a Kick off meeting;
2. Prepare the final design of the transducers, signal conditioners, sensors and adapt sensor supports to the specified thermal and radiation condition, and to the space allocation constrains; ;
3. Submit respective designs of transducers and supports to be reviewed by Port Integrators through the delivery of a design report;
4. Submit the manufacturing documentation (procedure, plans and drawings) as indicated in following chapters;
5. Submit a detailed qualification plan and qualification report for transducers;

6. Support the selection of the interrogation unit driver;
7. Provide qualification plan and qualification report;
8. Start manufacturing activities, upon acceptance through PDR/FDR gateway of items 1 to 5;
9. Support the installation and testing guidelines of transducers and interrogation units;
10. Fabricate or order all items for pre-series upon developed procedures and through all QA provisions;
11. Qualify the pre-series upon the planned qualification program;
12. Supply or order the series parts and fabricate the series upon developed procedures and through all QA provisions;
13. Test assembled items for factory acceptance;
14. Prepare the delivery readiness review of each delivery;
15. Ensure proper procedures are following for cleaning, packing, and shipping of components to IO site along with the required documentation.

2.2 Scope of the supply

RQ# 1 The contractor shall supply sensors to Port Plugs for the transducers summarized in . . These will allow measuring the acceleration of 3 upper port plugs in the three spatial directions (vertical, toroidal and radial), as well as the acceleration of 2 equatorial port plugs in the vertical and toroidal directions. For each port plug, the measurements shall be taken at two locations (lower and upper plates), placed at the same radial and toroidal coordinates.

RQ# 2 The contractor shall support the selection of the interrogators and splice box required for connecting each of the individual sensors indicated in . .

Table 1. Summary of the scope of the supply.

Component	Vacuum Quality Class (VQC)	Quantity installed	Spares	Total
1-D accelerometers with optical fibre ends	VQC 1B	2*(3*3+2*2) = 26	4	30

RQ# 3 The contractor shall supply supports allowing fastening three accelerometers in three orthogonal directions for Upper Port Plugs, as well as two accelerometers in toroidal and vertical directions for Equatorial Port Plugs.

2.3 Estimated duration

Estimated duration of this Contract is 24 months.

RQ# 4 During the duration of this contract, the contractor shall present the state of the task in each of the review gates with tentative dates shown in Table 2.

Table 2. Port plugs mechanical instrumentation review dates.

Review	Expected Date
PDR/FDR	6/21/2022
MRR	1/21/2023

3 Design requirements

Requirements listed as *RQ* shall be met by the design. Compliance shall be justified by reporting and eventually test and qualifications.

RQ# 5 The contractor shall provide a Verification Control Plan (VCP) also called compliance matrix showing, for each of the requirements in this Technical Specification noted RQ, how they intend to comply and verify compliance.

RQ# 6 The final design of sensors shall be reported in a design report including all required design description, drawings and diagrams and a revised VCP.

RQ# 7 At the end of the design phase, Installation guidelines shall be delivered to IO for both sensors and signal conditioners.

3.1 Sensor and fibres requirements

RQ# 8 Sensors should work on a light source with wavelength between 1500 and 1600 nm (possibly tuneable). This bandwidth is preferred to provide the smallest reasonable achievable degradation at irradiation, since the radiation-hard fibres demonstrate minimal radiation-induced degradation within this range. .

RQ# 9 The possible multiplexing of sensors on fibres should be considered in view of their location, thermal compensation and sampling rate requirement. Proposed arrays of sensors should be agreed by the IO at design stage.

RQ# 10 Both ends of any fibre will be spliced and available at the SCC to allow changing interrogation side for redundancy.

RQ# 11 Sensors shall include thermal compensation, either embedded to the transducer or by mean of local compensation.

RQ# 12 Sensors shall be maintenance free.

It is recommended to implement thermal compensation of sensors within the transducer. However temperature compensation may also be implemented at software level if there is a clear benefit on the capacity of instruments. In this case, additional temperature sensors shall be considered and may be sampled at a lower rate 1Hz and connected to slow controllers. In this case, the thermal compensation shall be immune to mechanical strain, sensitivity below 1%.

3.2 General design requirements

3.2.1 Transducers and sensor supports

Transducers are designed to monitor worst-case conditions including accidental events and survive shock waves if- and when the Port Plug will hit the Port. Normal loading conditions, incidents and accidental events include fast electromagnetic transients and induced forces, thermalization of the port plugs and seismic events. All of these induce motion of the Port Plugs relative to the VV.

RQ# 13 The transducers should include protection or adequate encapsulation to avoid any damage during installation and operation in case of humidity exposure.
RQ# 14 Transducers and their supports components shall sustain vibration and shocks.
RQ# 15 Supports shall be maintenance free.

There is no specific requirement and test specified. The sensor shall appear to be reasonably Strong; see Testing and qualification.

RQ# 16 The transducers delivered for qualification or installation shall be clean in a state relevant for immediate installation:

- Any adhesive tape attached to surfaces of the item whether or not they are to be exposed to vacuum must be removed and any adhesive residue carefully removed with the solvent isopropyl alcohol or ethanol according to [R11].
- Any marker pen or paint or similar on any surfaces of the item whether or not they are to be exposed to vacuum should be carefully removed by scraping if necessary followed by washing with the solvent isopropyl alcohol or ethanol and rinsing in demineralized water according to [R11].

RQ# 17 All materials shall have a relative permeability of less than 1.03.
RQ# 18 Halogen materials are not allowed.

Materials complying with the environment of the VV and Port Plug are listed in section 6.1.

RQ# 19 Transducers shall be compatible with Table 3.

Table 3. Transducers operating conditions

Type	Survival temperature range (°C)	Operating temperature range (°C)	Irradiation, total dose (MGy)	Irradiation, neutron fluence, ΦE>0.1 MeV (n/cm2)	Max. H isotopes outgassing rates ($Pa.m^3/s/m^2$)	Max. impurities outgassing rates ($Pa.m^3/s/m^2$)
Accelerometer	0-250	20-170	20	$3 \cdot 10^{17}$	10^{-7}	10^{-9}

RQ# 20 All sensors will thermally compensate to allow measurements within the required accuracy over the full operating temperature range.
RQ# 21 Wavelength drift on FBGs due to high temperature operation shall be negligible and lower than 30% of the requirement of accuracy.
RQ# 22 The survival limit for accelerometers of the Upper Port Plugs shall be not less than +/- 50 g (harmonic loading, 10**4 cycles).In the case of the accelerometers of the Equatorial Port Plugs this limit shall be no less than +/-20g).
RQ# 23 Selected materials shall be compatible with temperatures ranges as per Table 3 without permanent damage.
RQ# 24 Design and materials shall be compatible with a total absorbed dose as per Table 3 (total absorbed dose of gammas).
RQ# 25 Design and materials shall be compatible with a total fast neutron fluence as per Table 3 (neutron fluence, ΦE>0.1 MeV).
RQ# 26 For any of the previous two requirements, the transducer and optical fibres' attenuation shall be <0.2 dB/m.

RQ# 27 Design and materials of all strain gauges, accelerometers and their supports shall be compatible with 500 cycles from 100°C to their respective maximal operating temperature at a rate of 10°C per hour.

RQ# 28 Design and materials of all strain gauges, accelerometers and their supports shall be compatible with their respective maximum temperature for 20 000 h.

RQ# 29 Design and materials of all strain gauges, accelerometers and their supports shall be compatible with a normal operating temperature of 100°C for 120 000 h.

RQ# 30 Design compatibility with the thermal operating conditions shall be demonstrated by qualification and may proceed by accelerated thermal ageing. In case of accelerated thermal aging at temperature higher than 200°C, an additional thermal test shall be conducted to determine the drift at 200°C.

RQ# 31 Electro-magnetic conditions (In a sense that resultant EM loads may impact cross talk):

a. Maximum field during operations, Bt = 4T,
b. Maximum survival transient field variation, Bp/dt = 2T/s (@ Bt = 4T)

3.2.2 Vacuum requirements

The following applies to transducers and sensor supports to be installed in the Port Plugs.

RQ# 32 Transducers and their supports shall have an outgassing rate of less than 10^{-7} Pa.m³/s/m² at 100°C for hydrogen isotopes.

RQ# 33 Transducers and their supports shall have an outgassing rate of less than 10^{-9} Pa.m³/s/m² at 100°C for impurities.

RQ# 34 Transducers and their supports shall not trap any volume (air or other species) I.e., the housing of transducer shall feature vents to prevent trapped volumes.

RQ# 35 An outgassing test shall be performed at design stage if products or materials proposed as part of the design of transducers and supports used in the Port Plug do not meet at least one of the following conditions:

- All materials or products are listed in [R11] or accepted by derogation
- All materials or products are used in a similar application or registered in a relevant material database (e.g [R12], [R11]) with an equivalent total mass loss equivalent to an outgassing rate below 10^{-9} Pa.m^3/s/m^2).

RQ# 36 Materials shall be limited to the list of approved and restricted materials in Appendix B and [R11].

RQ# 37 Supplementary materials not already listed in [R11] could be approved upon a request of derogation to be duly approved by the IO.

3.3 Accelerometers specific requirements

3.3.1 Performance requirements

RQ# 38 The lowest accurately enough (*) measured acceleration to be as low as 0.2g as design requirement and pursue 0.1g as design goal for upper port accelerometers, while for the equatorial port, these values will be 0.1g and 0.05g respectively;

RQ# 39 Sensitivity in the direction of the measurement 0.05g as design requirement and 0.02g as design goal for the upper port accelerometers. The required sensitivity of the equatorial ports accelerometers shall be of 0.025g, with a design goal of 0.01g;

RQ# 40 Sensitivity to off-axis accelerations (*) to be <3% as design requirement and pursue <1% as design goal to that of in-axis measurements for all frequencies;

RQ# 41 The first Eigen frequency of the mechanical part should exceed 800Hz;

(*) The lowest accurately enough measured acceleration for each sample will be quantified from the obtained graphs of the noise (in the bandwidth from 3Hz to 500Hz), linearity and a level of cross talk, all as functions of amplitude and frequency of the applied acceleration. Specific definition for "accurate enough measurement" is proposed here as <3 % for each of these three parameters. When these output graphs obtained and compared, present quantitative definition of performance requirements may be re-discussed and adjusted reasonably.

3.3.2 Integration requirements

RQ# 42 Dimensions of the protective case, shall fit in 59*65*(15~25) mm, being the first dimension in perpendicular direction to the port wall. Additional attachment feature shall not increase the dimension of 59mm.

RQ# 43 The accelerometers shall have location and attachment features allowing their installation as agreed with the CRO.

RQ# 44 Connectors will be contained within the port structure plane, and parallel to the port plug axis.

RQ# 45 Up to two variants of accelerometers may be delivered in order to comply with the previous three requirements. In this case, all of the accelerometers will comply with the most stringent requirements either from upper port or equatorial port, in a way that not more than two variants will be required for all ports.

RQ# 46 One single fibre may connect 6 1-D accelerometers with additional temperature sensor at each group of three. This loop-style connection minimizes the chance of losing all sensors in case of a one-point fibre failure anywhere along the series of sensors (see Figure 1, middle and lower schemes).

RQ# 47 Sensor connectors and dead-ends of the fibres will avoid back-reflection of wave.

RQ# 48 The accelerometers will be supplied with the required length of fibre for the performing the connection at the splicing box located inside the port plug (2-5m, depending on the port).

RQ# 49 Recommendations on specific interrogator requirements for the implementation of the loop connection are given in Figure 1.

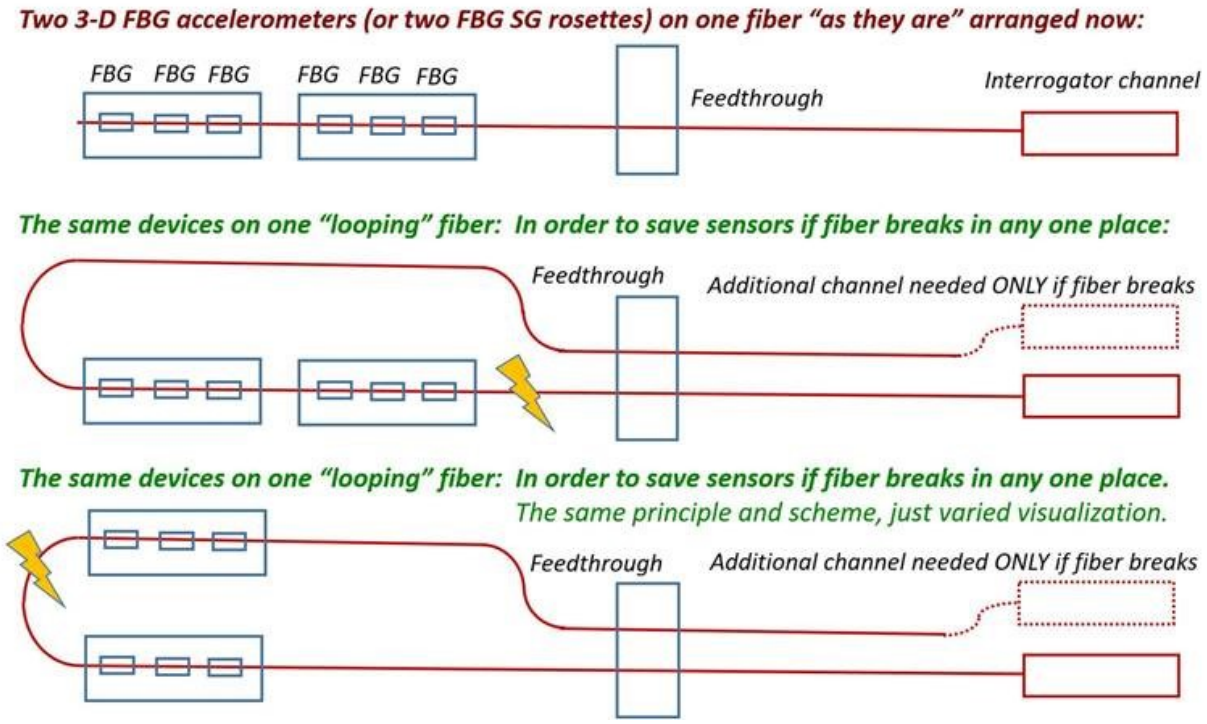

Figure 1. Connection schemes for sensors. Upper: typical scheme to be changed to looped version shown in mid and lower schemes.

3.4 Optic fibre specific requirements

RQ# 50 Optic fibre shall have maximum diameters and tolerances as shown in Table 4.
RQ# 51 The optical wire shall be routed considering a minimum bending radius of 15 mm
RQ# 52 The optical fibres shall be protected with an external stainless steel or nickel tube, with 2.4 mm outside maximum diameter.

Table 4. Single-mode radiation-resistant fibre parameters

Mono-mode fibre		
Core diameter	6.5± 0.5	um
Cladding diameter	125.0 ± 1.0	um
Coating diameter	160.0 ± 5.0	um
Bending Radius	15	mm