Integrating a distributed antenna in DEMO: requirements and challenges

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Integrating a distributed antenna in DEMO: requirements and challenges

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The use of efficient heating and current drive (H\&CD) systems is an important research priority for DEMO. The ion cyclotron range of frequency (ICRF) system is a promising candidate given decades of proven operational experience and low price equipment up to the MW level. ICRF antenna is presently situated in a port of limited size in the vacuum vessel (VV), which may be accompanied with operational limitations in DEMO, primarily because such configurations present high power density structures that can undergo malfunctions for the power levels anticipated for DEMO, because of voltage standoff limitations. To mitigate this, a novel ICRF antenna is under development and consists of toroidally distributed identical radiating straps integrated inside the blanket First Wall (FW). Given the antenna concept novelty and the strict requirements on the performance of DEMO, substantial design and integration efforts are needed. This paper highlights the requirements on the ICRF antenna and the challenges facing its integration in DEMO.

Keywords: Ion cyclotron range of frequency (ICRF), distributed antenna, breeding blanket, tritium breeding ratio, blanket remote handling

1. Introduction

The ICRF is an established method for H\&CD in several fusion facilities, and will be used in ITER for similar purposes \cite{1}. ICRF is also one of the heating methods considered for DEMO.

ICRF antenna in its present configuration is shown in figure 1 and consists of few (or many, e.g. 24 for ITER) poloidal current straps, integrated in a port of limited size in the VV or within an antenna frame, in the machine. Such configuration carries with it a few drawbacks: (i) reduced coupling due to the evanescence of ICRF waves in the low density edge of plasma, (ii) possible high Z impurity release due to generation of larger sheath potentials due to RF, resulting in accelerated ions producing surface sputtering, and (iii) possibility of voltage arcs or breakdown because high strap voltages and current amplitudes are needed to radiate the total required power, resulting in a high power density system. These drawbacks of present antenna configuration make the exploitation of ICRF increasingly challenging for DEMO. Alternatively, a novel ICRF concept is currently under development \cite{2a, b} and \cite{4, 5, 6}, constituted of identical poloidal current straps covering 360° toroidally of the wall, as shown in figure 2a,b. Such antenna optimizes the coupling to the plasma because: (i) for a given inter-distance between the straps, the array coupling scales proportionally to the total strap number: this allows the coupling of large amount of power with affordable voltage and current constraints \cite{4, 5}, (ii) the absence of vertical septa between the straps leads to a significant increase of coupling with respect to a conventional antenna where the septa are inserted to reduce mutual coupling effects, and (iii) The radiated power spectrum can be very selective in the best k\nu for coupling and heating \cite{5, 6}. Furthermore, such antenna potentially

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avoids, to a large extent, with its 360°
symmetry, the occurrence of induced currents
at non-intended location, which would lead to
RF electrical fields, sheaths and additional
impurity production.

DEMO imposes stringent challenges on the
integration on this novel antenna design not
faced by its predecessor (e.g. ITER). The novel
ICRF antenna will have to respect certain
boundary conditions related to the breeding
blanket (BB) such as not to impair its functions
of neutron shielding and tritium breeding,
being able to match the blanket modularity and
have same power handling capabilities during
operation as the blanket FW. The antenna must
also be fully compatible with the remote
handling (RH) procedure for the blanket.

The configuration of the distributed antenna,
suggested feeding concept, and the most
significant points related to its integration in
DEMO are highlighted in section 2.

2. Distributed ICRF antenna configuration
The novel distributed antenna is planned to be
made of identical toroidal array sections of a
limited poloidal extent, which can be
contiguous to cover the complete wall
periphery. Straps will be placed inside a
recession and covered by the FW, which will
be slotted in the toroidal direction and acts as a
Faraday Shield (FS). The dimensions of the
recession and of straps are yet to be optimized,
but typical presently suggested values are
assumed: the recession will be 100 cm
poloidally and 20 cm deep. Inside, there will
be a ring array of ~20 cm width straps (toroidal
direction) separated by ~3-4 cm each (the final
separation is still to be defined.). The thickness
of the antenna will be ~2 cm. For neutronics
calculations a composition of antenna 10% +
vacuum 90% is considered to be a good first
assumption (the antenna is then considered as a
mix of different layers of materials the straps
may be made from, and any coolant material
that may be used inside) [3]. Figure 2a,b shows
part of the antenna in one blanket sector. The
antenna will be situated at a poloidal position
between the vertical and equatorial ports. Final
position will be influenced by a trade-off
between physics functionality and engineering
constraints.

2.1 Antenna feeding
One feeding concept discussed here, which
avoids the necessity to feed and match each
strap separately. Feeding is periodically done
on sections of the array, with each blanket
sector fed with a number of transmission lines
(TLs) in a resonant ring configuration (figure
3) [4, 5, 6]. This system has many advantages:
(i) only the first and last straps of each array
section are connected to an external line, (ii)
the generators remain matched for all loading
conditions and is therefore load resilient. The
actual feeding scheme, with the location of and
number of feed lines to the straps to be fed per

Fig.1. Example of present ICRF antenna
corfiguration as seen on JET. On the right, the
ITER Like Antenna (ILA), a high power density
antenna, situated in a port of limited size
toroidally and poloidally. In the middle, JET
ICRF antenna, positioned in a frame inside the
vessel. On the left is a Lower Hybrid (LH)
antenna, not discussed here (figure adapted
from [7]).

Fig.2a: View of ICRF antenna in one
blanket sector (FS shown on left blanket segment
for illustration, but exists on all segments); and
2b: radial build showing one strap integrated
in the FW recession. Top and bottom parts of
the strap form a capacitor configuration with
the blanket, middle segment acts as a short
circuit with the blanket. It also acts as a
structural support and an inlet-outlet for the
straps coolant.
The blanket sector is still under assessment. Possible approaches could be that for one blanket sector, two straps per central outboard blanket segment (COBS), cf. figure 3a, or (ii) the outermost straps in the left outboard blanket segment (LOBS) and right outboard blanket segment (ROBS) are fed as shown in figure 3b. The number of straps in each blanket sector must be chosen in order to avoid too large strap current decay between the first and last strap of each section [5]. The materials used for antenna straps will likely be similar to the blanket FW and BB structural materials itself, since, among other loads, it will receive the same neutron fluence. Exact materials composition will be decided based on ongoing integration and optimization studies. The feeding lines will have to be routed through the vertical ports down to the blanket segment where straps are located. Two lines are presently assumed to interface with each active (i.e. fed) strap, although one may also suffice. Optimum routing of lines via vertical ports needs to be assessed based on space available and neutron irradiation considerations. The materials of the feeding lines are likely the same as the BB structural material with a thin conducting layer (likely Cu). The materials can be chosen to take into account the high temperature and neutron irradiation. Ceramic windows will present to separate the pressurized lines segments from those under vacuum. They can be installed behind dog-leg structures (of transmission line itself) and neutron shields. Another issue is the insulating material in the coaxial TLs, which position the inner conductor inside the outer conductor, and are made from ceramics. The choice of material type for the electrically insulating component and its location along TLs will be a trade-off between avoiding long lines under vacuum and potential loss of performance under the high neutron environment found in DEMO.

3. Constraints imposed by DEMO

Implementation of the novel ICRF antenna in DEMO may require laborious integration effort, and possible optimization of the initially assumed antenna configuration (described in section 2), in particular with the breeding blanket. The following is a description of the primary integration issues of an ICRF antenna in DEMO. The points described are not meant as a comprehensive list that covers all integration related issues, but rather a highlight of those having prime priority at this initial design stage.

![Fig.3a COBS feeding and 3b. ROBS and LOBS feeding.](image)

3.1 Hosting breeding blanket

Since the antenna is integrated in the blanket, it must ensure the tritium breeding and neutron shielding functions of the blanket are not hindered or degraded. Furthermore, the structure also should keep the complexity of the overall design at minimum, by e.g. sharing the cooling circuit with the blanket. Such requirements will have to be realized independent of which blanket type is eventually chosen for DEMO, though integration studies at this stage will focus on a single concept (likely the helium cooled pebble bed will be selected for initial integration studies).

DEMO is required to be a machine which ensures fuel self-sufficiency. Thus special attention was given to this issue in an earlier study [3] which investigated the effects of an ICRF antenna on the tritium breeding ratio (TBR), and provided an already encouraging case for the antenna integration in terms of TBR: with a total straps area of 70 m², loss of TBR was equivalent to a 1.4 m² opening in the VV equatorial plane, a factor of 50 less in area (namely, ΔTBR does not exceed in the extreme cases (based on a parametric study) a value of 0.006). The TBR calculation will need to be refined when better definition of the antenna and its feeding becomes available (results reported in [3] do not, for instance, take the
TLs that feed the straps into account). Another important factor related to the antenna integration in blanket is the structural integrity of the antenna. It must be ensured under both steady state and transient load conditions (e.g. plasma disruptions, vertical displacement events (VDE’s), etc.).

3.2 Remote handling compatibility

Remote maintenance of the blanket is foreseen through the vertical ports following a specific process, where every blanket segment is treated separately from the others using remote handling equipment, and are lifted outside the VV for maintenance through DEMO’s vertical ports. This is illustrated in figure 4. From the antenna straps perspective, this requires that no toroidal connection between the straps should exist, and hence the blanket segments must remain modular. Additionally, the antenna must be as reliable as blanket FW itself, so that the reliability of the blankets is not reduced, and is desirable from RH perspective. From the TLs perspective, the presently foreseen dimensions (12 or 9 inches in diameter) are considered challenging; hence an effort will be made to ensure further optimization of the TL size. Another requirement is to use TLs with long segments (known as large replaceable line segments) when possible, to reduce the number of maintained segments and hence potentially the overall maintenance time. Since part of the TLs will operate under vacuum by implementing ceramic windows, solutions for optimum placing of the windows along the TLs should be defined.

4. Conclusions and future outlook

This paper highlighted the necessity for a new ICRF system configuration for practical realization in DEMO. Focus is given on the distributed antenna. Any foreseen ICRF structure in DEMO needs to be compliant with other systems; of prime importance are the breeding blanket and remote handling procedures attached to it. Engineering design and integration of antenna is now an ongoing process, aiming to provide a consistent initial concept of an ICRF system in DEMO.

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