Status of the 2 MW, 170 GHz Coaxial Cavity Gyrotron for ITER

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OUTLINE

• **introduction**
  ▶ frame and goal

• **industrial prototype of 170 GHz, 2 MW, CW coaxial cavity gyrotron**
  ▶ design characteristics and status

• **experimental pre-prototype of the 170 GHz coaxial cavity gyrotron:**
  ▶ recent experimental observations and results
    - LF oscillations; operation with spherical load; influence of stray radiation;
    q.o. RF- output system and performance of the RF output beam

• **summary and outlook**
frame and goal

- As cooperation of European research centres - FZK Karlsruhe, CRPP Lausanne, HUT Helsinki, ... - with the European tube industry (Thales ED, Velizy, France) a

2 MW, CW, 170 GHz coaxial cavity gyrotron for ITER is under development. A contract for procurement of a first industrial prototype has been signed in June 2004 between EFDA and Thales ED

- A superconducting magnet has been ordered and is under fabrication

- A gyrotron test facility has been constructed at CRPP Lausanne

- A 170 GHz short pulse (few ms) experimental coaxial gyrotron (pre-prototype) at FZK has been used to validate the design of main gyrotron components and to investigate possible problems
170 GHz, 2 MW prototype and experimental pre-prototype coaxial gyrotron
- design specifications -

2 MW, CW prototype

- operating cavity mode: $\text{TE}_{34,19}$
- frequency: 170 GHz
- RF output power: 2 MW
- generated RF output power: 2.2 MW (10% internal losses assumed)
- beam current: 75 A
- accelerating beam voltage: 90 kV
- cavity magnetic field: 6.87 T
- velocity ratio: 1.3

$\sim 5 \text{ ms}$ pre-prototype *

$\sim 1.5 \text{ MW}$ *

$80 \text{ kV}$ *

$\sim 6.70 \text{ T}$ *

{ * due to field limitation of the SC-magnet available at FZK!}
170 GHz coaxial cavity gyrotron and components

- collector
- mirrors
- RF beam
- launcher
- ceramic insulator
- view into the mirror box
- beam tunnel
- cathode
the prototype coaxial cavity gyrotron with the RFCU unit as installed in the test facility at CRPP Lausanne in a dummy of the SC magnet
schematic view of the SC - magnet

- **solenoid coils**
  - design values: \( B_{\text{cav}} = 6.87 \text{ T} \)
  - warm bore hole: \( \varnothing = 220 \text{ mm} \)
- **dipole coils**
  - solenoids: 2 main coils, 1 cancellation coil, 2 gun coils
  - dipole coils: 2 sets of x and y coils
view of the assembled SC - magnet

- vacuum leak tests performed these days

  further possible scenario:
  - factory tests finished until ~ end June
  - on site installation and tests; until ~ mid of July
  - begin of gyrotron tests: end of July
the first prototype of the coaxial gyrotron has been fabricated and delivered to CRPP Lausanne

the gyrotron test facility constructed at CRPP Lausanne is ready for operation

The gyrotron has been installed in the test facility in a dummy of the SC magnet. All auxiliary installations have been performed and technical tests are completed.

the delivery of the SC magnet is delayed !!!
- assembling of the SC magnet finished, factory acceptance tests are starting !!!

SC magnet could be available for gyrotron tests ~ end of July 2007 !!!
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• summary and outlook
short pulse pre-prototype 170 GHz coaxial cavity gyrotron

- similar as in prototype tube -

electron gun
- similar as in prototype tube -

launcher and mirrors
- same as in prototype tube -

cavity: - same as in prototype tube -

anode; +30kV

cathode with emitter; -50kV

insert; +30kV
- fixed part -

insert; +30kV
- adjustable part -

ceramic insulators

output window

RF beam

phase correcting mirror

toroidal mirror

quasi-elliptical mirror

launched

parabolic smoothing

4 mm

impedance corrugation
70 grooves (rectangular)
width L = 0.35 mm
depth d = 0.44 mm

corrugations: w = 119
parasitic LF oscillations at ~ 260 MHz and ~330 MHz
geometry and calculated resonant LF field distribution at $f_{LF} = 261$ MHz

- simulations with "CST microwave studio"

$=>$ mechanism of the LF oscillations has been recognized and actions for reducing the oscillations have been taken and verified
mechanism of LF generation
- experimental verification of the hypothesis -

- transit time $t_{tr}(U_b=35 - 80kV) = 3.9 - 3 \text{ ns}$
- axial LF field component due to small steps of the insert radius
- cathode with LF field

$\text{cavity}$

$I_{\text{start}}(\text{LF}) > 40 \text{ A}$

$I_{\text{start}}(\text{LF}) \sim 12 - 15 \text{ A}$

$\Rightarrow \text{amplitude of LF oscillations significantly reduced} !!!$
operation with the spherical microwave load developed by ENEA/CNR for use with the 2 MW, CW 170 GHz gyrotron

- amount of microwave power reflected back into the gyrotron
ENEA/CNR spherical load with preload
FZK calorimeter (~ Brewster load) behind preload
interface between gyrotron and load as foreseen for the prototype

power reflected back into the gyrotron is determined by measuring the change of the level of stray radiation ($\propto$ power through relief windows) inside the gyrotron!!
RF power reflected back into the gyrotron in a non directed way results in an increase of the level of stray radiation (∝ power through relief windows) inside the gyrotron!!
microwave power from a relief window

Level of stray radiation $dR_{bolo}/t_{pulse}$ vs. beam voltage $U_c$. All other parameters constant

- reference (internal losses): $P_{stray} \approx 8\%$;
- interface with Brewster load: $P_{stray} \approx 10.4\% \Rightarrow$ reflected power $P_{refl} \approx 2.4\%$ of $P_{out}$
- interface with spherical load: $P_{stray} \approx 11.6\%$; $\Rightarrow$ reflected power $P_{refl} \approx 3.6\%$ of $P_{out}$
microwave power from a relief window

\[ P_{\text{refl}} \cong 0.11 \times 8\% \cong 1\% \]

Level of stray radiation \( dR_{\text{bolo}} / t_{\text{pulse}} \) vs. beam voltage \( U_c \). All other parameters constant

=> power reflected from the spherical load: \( P_{\text{refl}} \cong 0.11 \times 8\% \cong 1\% \)
influence of the level of stray radiation inside the gyrotron on RF generation
influence of stray radiation on RF generation

- An increase of stray radiation causes a strong reduction of $P_{\text{out}}$ and some reduction of $U_{\text{max}}(\text{TE}_{34,19})$.

Influence of decrease of the level of stray radiation on RF generation will be studied experimentally.

<table>
<thead>
<tr>
<th>$P_{\text{stray}}/P_{\text{out}}$</th>
<th>$U_{\text{max}}(\text{TE}_{34,19})$</th>
<th>$P_{\text{out}}$ (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08</td>
<td>74.8 kV</td>
<td>1</td>
</tr>
<tr>
<td>$0.08 + 0.12 = 0.2$</td>
<td>72.5 kV</td>
<td>0.65</td>
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<td>0.08</td>
<td>72.8 kV</td>
<td>1</td>
</tr>
<tr>
<td>$0.08 + 0.025 = 0.105$</td>
<td>72.8 kV</td>
<td>0.85</td>
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</table>
quasi-optical RF output system

presently used system:

- launcher with $\Delta m = 2$ and $3$ and one phase correcting mirror

=> poor performance (very low Gaussian content of the RF output beam)

under test:

- launcher with $\Delta m = 3$ only and one phase correcting mirror

=> from simulations a Gaussian content in the RF output beam of ~ 88% is expected !!!

final goal:

- an improved system delivering an RF beam with Gaussian content $\geq 95$

and stray losses < 5 %
RF output beam (amplitude and phase) at position of the RF output window - calculated -

- launcher with only 3rd azimuthal corrugation, $\Delta m = 3$ and one phase correcting mirror

=> Gaussian content (calculated): ~ 88% : hot measurements are going on now !!
summary and outlook

1st prototype of a 2 MW, CW 170 GHz coaxial cavity gyrotron
- the prototype gyrotron has been fabricated and delivered to CRPP Lausanne end of 2006
- the test facility is ready for operation
- the SC magnet: factory acceptance tests are expected to start this week! SC magnet could be available for gyrotron experiments mid of July 2007
- gyrotron tests: August 2007 – February 2008

operation of the 170 GHz pre-prototype coaxial cavity gyrotron
- parasitic LF oscillations: - mechanism identified and hypothesis verified experimentally
- microwave load: - the performance of the spherical CNR load has been measured
  power reflected from the load ~ 1%; from the preload ~ 2.5%
- RF generation: - increased level of $P_{\text{stray}}$ reduces efficiency of RF generation and the range of operation
- q.o. RF output system: - the RF system used at present is not satisfying, the Gaussian content of the RF beam is too low!
  - improved q.o. RF output system under investigation