Module performance at TTF

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Outline

– Operation periods of modules at TTF
– Gradient performance of full modules
– Problems during module assembly
– Conclusion
Operation periods of accelerating modules at TTF

- Capture Cavity
  - Since 1996
- M1
  - built in February 1997
  - March 1997 – March 1999
- M2
  - built in September 1998
  - September 1998 - April 2002
- M3
  - built in April 1999
  - July 1999 - April 2002
- M1*
  - rebuilt M1, removed cavities with bad EB welds
  - built in February 2000
  - June 2002 - November 2002
- M Superstructure (2x (2x7))
  - built in May 2002
  - June 2002 - November 2002
Next Module Tests

- three new accelerator modules
- ACC3 to ACC5 (3*, 4, 5)
- and later this year another two
- ACC1 and ACC2 (2*, 1*)
Results

• Accumulated more than 13000 hours of operation
• Operation of modules very flexible with a variety operating gradients
• Typical FEL average operation gradient was around 14-17 MV/m
• Maximum average gradient with beam was 22.4 MV/m in M3
• Stable operating gradient around 20-21 MV/m in M3 and M1*
Module gradients

<table>
<thead>
<tr>
<th>Module #</th>
<th>Gradient [MV/m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
<td>2</td>
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<tr>
<td>3</td>
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<tr>
<td>1*</td>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

- Cavity Test (Vertical) Q >=1e10
- Stable Module RF Operation
- Stable Beam Operation
- Max. Gradient with Beam
Cavity performance

- observed that a few cavities perform significantly in module lower than in tests (cw and high power)
- due to additional attenuation in the waveguide distribution system the impact of this degradation could be reduced, but for M1* performance below expectations
Example: Single Cavity results M1*

Module 1*

- Cryostat tests:
  - Vertical
  - Horizontal
  - Module

Graph showing the electric field $E_{ACC}$ [MV/m] for different cavities labeled 1-S31, 2-C44, 3-C46, 4-S36, 5-D2, 6-A18, 7-D1, 8-A17. The graph indicates a comparison of vertical, horizontal, and module tests.

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Review of assembly procedures

• after the degradation of a few cavities has been identified a review of assembly procedures took place

• try to…
  – find all problems in the different assembly steps (e.g. cleanroom, coupler, cryostat)
  – give a ranking of critical points during assembly
    • Very critical
    • Critical
    • Less critical, but still annoying or inconvenient

• result:
  – especially the assembly of the warm coupler part turned out to be critical
  – several assembly procedures need to be defined in more detail
Problem count on modules

![Bar chart showing problem counts on different modules.](chart.png)
Other lessons learned

• Leaks
  – Sealing of first cavity series insufficient
  – Ceramic feedthroughs for pick-ups at couplers and BPMs are the major source -> eventually use titanium instead of steel
• Adjustment needs improvement, esp. of the cold mass to cryostat
• Changes of the design in one part need to be evaluated on the impact of the whole assembly
• Tight schedules led to use of untested parts (e.g. couplers -> longer processing)
• Long timescale from building a module to its test looks problematic (slow feedback)
• Shorts
  – Pickups
Conclusion

• a lot of experience running superconducting modules has been accumulated

• accelerating modules have shown gradients of more than 20 MV/m with beam

• a few cavities have shown performance degradation
  – assembly procedures are being reviewed (esp. coupler)
  – an improved error tracking protocol needs to be implemented

• still some work needed to go from the R&D phase to the mass production
Old Conclusion

- Some cavities/couplers show a degradation in performance after non-standard treatments (e.g. C2 in M1*, C6 in M1*)
- Module 1* shows high problem count, but selection is still subjective, needs for further input
- It remains difficult to pinpoint reasons for degradation, because:
  - Hard to get an overview
    - Several locations were relevant information is stored
    - No consistent format even within one assembly step
    - Missing information
    - Post-operation analysis difficult, example: no detailed leak search in M1* yet
Conclusion II

– Long time-scale from assembly to measurement is not good for a fast feedback into the assembly process.
– A complete description of all steps is urgently needed, to evaluate the impact:
  • Problems occurring during assembly e.g.:
    – How critical is a problem in terms of cavity/coupler/module performance?
    – What is the stage to fall back to after a problem?
    – Scheduling
    – etc.
  • Design changes of components
Overview Q(E) modules
Individual cavity results: LINAC vs. Vertical

\[ y = 0.9119x \]

\[ R^2 = 0.3913 \]
CHECHIA vs. Vertical

$$y = 0.99x$$

$$R^2 = 0.1765$$

Acceptance test $E_{acc}[\text{MV/m}]$

High power test in CHECHIA $E_{acc}[\text{MV/m}]$
LINAC vs. CHECHIA

High power test in CHECHIA $E_{\text{acc}}$ [MV/m]

$y = 0.9x$

$R^2 = 0.3305$

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Module 2 Single Cavities test results.

Cryostat tests:
- Vertical
- Horizontal

Cavities:
- 1 - C22
- 2 - C21
- 3 - C25
- 4 - C23
- 5 - A15
- 6 - C26
- 7 - C27
- 8 - C24

Denis Kostin. MHF-SL.
# Module 2 (ctd.)

<table>
<thead>
<tr>
<th>Module Cavity</th>
<th>Couple Cleanroom Leaks</th>
<th>Add. A Blue</th>
<th>Green</th>
<th>Coupler assembly Pickup Warm</th>
<th>Cold pLeaks</th>
<th>Blue</th>
<th>Green</th>
<th>Cryostat Pickup Leaks</th>
<th>Adjust. Blue</th>
<th>Green</th>
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<tbody>
<tr>
<td>2 C22</td>
<td></td>
<td>4</td>
<td>1</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>C23</td>
<td>High activity</td>
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<td>1</td>
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<tr>
<td>A15</td>
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</table>

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TESLA

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Module 3

Cryostat tests:
- Vertical
- Horizontal
- Module

E_{Acc} [MV/m]

Cavity

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20.11.2001

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### Module 3 (ctd.)

<table>
<thead>
<tr>
<th>Mod Cavity</th>
<th>Coupler perf</th>
<th>Cleanroom Leak Add.</th>
<th>Blue</th>
<th>Green</th>
<th>Coupler assembly Picku Warn Cold Leak Blue</th>
<th>Green</th>
<th>Cryostat Picku Leak Adjus Blue</th>
<th>Green</th>
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<tbody>
<tr>
<td>3 D41</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>S29</td>
<td>Coupler breakdown, no HV</td>
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<td>2</td>
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</tbody>
</table>

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Module 4

Cryostat tests:
- Vertical
- Horizontal

Vertical: E_{\text{ACC}} \text{ [MV/m]}

Cavity
1 - C48
2 - S34
3 - AC57
4 - AC56
5 - AC55
6 - AC59
7 - Z52
8 - AC64

20.11.2001

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## Module 4 (ctd.)

<table>
<thead>
<tr>
<th>Module</th>
<th>Coup Cleanroom</th>
<th>Coupler assembly</th>
<th>Cryostat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Leak/Add. Blue</td>
<td>War Cold Blue</td>
<td>Picku</td>
</tr>
<tr>
<td>4</td>
<td>Green</td>
<td>Leak Cold Blue</td>
<td>Leak</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green</td>
<td>Adjus</td>
</tr>
</tbody>
</table>

### High X in CHECH

- **Module 4**
  - Coup Cleanroom: High X in CHECH
  - Coupler assembly: 1
  - Cryostat: 1

### High X in CHECHIA

- **Module 4**
  - Coup Cleanroom: 1
  - Coupler assembly: 1
  - Cryostat: 1

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Module 5

Cryostat tests:
- Vertical
- Horizontal

<table>
<thead>
<tr>
<th>Cavity</th>
<th>E_{Acc} [MV/m]</th>
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</thead>
<tbody>
<tr>
<td>1 - AC62</td>
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<tr>
<td>2 - AC61</td>
<td>25</td>
</tr>
<tr>
<td>3 - AC65</td>
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<tr>
<td>4 - AC66</td>
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<td>5 - AC79</td>
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<tr>
<td>6 - AC77</td>
<td>25</td>
</tr>
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<td>7 - AC63</td>
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<td>8 - AC60</td>
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20.11.2001

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21.01.2003
## Module 5 (ctd.)

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<thead>
<tr>
<th></th>
<th>Coup Cleanroom</th>
<th>Coupler assembly</th>
<th>Cryostat</th>
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<tbody>
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<td>Module 5</td>
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<tr>
<td>Leak Add.</td>
<td>Blue Green</td>
<td>Pick Warr Cold</td>
<td>Pick Leak Adjus Blue Green</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

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Nan data

- Average Gradient for Module 3 RF only, November 1999
- Average Gradient for Module 3 with beam, April 2002

- Stable RF operation, 10 Hz rep rate, 11 hours
  At 22,5: 3 cavities above 23.8 MV/m
- RF operation, 10 Hz rep rate, 3 hours
  5 cavities above 23.8 MV/m

- Stable at 1 Hz with beam for 6 days (first week of May 2002):
  9 trips - 1 cavity at 23.7 MV/m
- Maximum gradient achieved with full beam, 1 Hz rep. rate,
  6 cavities above 23.8 MV/m
Single cavity error count

\[ y = -0.0527x + 4.8244 \]
\[ R^2 = 0.0152 \]

\[ y = -0.0995x + 1.6221 \]
\[ R^2 = 0.0678 \]

\[ y = -0.0358x + 1.4924 \]
\[ R^2 = 0.0102 \]
Idea

• Concentrate on M2, M3, M1*, M4, M5, exclude prototype modules (Susu, Module 1)

• Get all information about the module assembly available

• Ranking of critical points during assembly
  – Very critical
  – Critical
  – Less critical, but still annoying or inconvenient

• Try a correlation to the cavity performance

• Try to improve the module assembly procedure
Documentation about the Module Assembly

• There exist protocols (in a variety of formats and different levels of detail) for
  – cleanroom assembly
  – module assembly
  – coupler assembly
  – coupler processing
  – cryoload measurements

• There exists no…
  – complete documentation for the assembly procedure from individual cavity state to module in the linac
  – complete list of procedures (‘How-to’) for some assembly steps
  – detailed definition for the interfaces from one assembly step to the next

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# Example: Problem count Module 1*

| Cavity Module | Perf | Difficult | Per | Leaks | Add. | Blue | Green | Coupler assembly | Pickup | Warm | Cold p Leaks | Blue | Green | Pickup | Leaks | Adjust | Blue | Green | Leaks | Adjust | Blue | Green | Leaks | Adjust | Blue | Green |
|---------------|------|-----------|-----|-------|------|------|-------|-------------------|--------|------|-------------|------|-------|---------|-------|--------|------|-------|--------|--------|------|-------|--------|--------|------|-------|--------|--------|------|-------|--------|--------|
| 1*            | D    | -10 to CHECH Most difficult | 1   | 1     | 1    | 1    | 1     | 1                | 1      | 1    | 2           | 1    | 3     | 1       | 1     | 1      | 2    | 3     |       |        | 3       |        |      |       |        |        |
|               |      | -5 to CHECHIA                   | 1   | 1     | 1    | 1    | 1     | 1                | 1      | 1    | 2           | 1    | 3     | 1       | 1     | 1      | 2    | 3     |       |        | 3       |        |      |       |        |        |
|               |      | -6 to CHECHIA Difficult         | 1   | 1     | 1    | 1    | 1     | 1                | 2      | 1    | 2           | 1    | 3     | 2       | 1     | 1      | 2    | 3     |       |        | 3       |        |      |       |        |        |
|               |      | -4 to CHECHIA                   | 1   | 1     | 1    | 1    | 1     | 1                | 1      | 1    | 3           |      |        | 1       | 1     | 1      | 3    | 3     |       |        | 3       |        |      |       |        |        |

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Problems on modules / Leaks

- Leaks in all modules in linac except Superstructure
  - Feedthroughs (8x)
  - Flanges (2x)
  - Helium tanks (2x)
  - Coupler ceramics (2x)
# Summary of Vacuum Leaks in Modules

<table>
<thead>
<tr>
<th>Linac Section</th>
<th>Module 1 ACC1</th>
<th>Module 2 ACC2</th>
<th>Module 3 ACC1</th>
<th>Module 1* ACC2</th>
<th>Super Structure ACC1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Leaks</td>
<td>1</td>
<td>6</td>
<td>7</td>
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<tr>
<td>Insulation to beam pipe</td>
<td></td>
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<tr>
<td>Cavity flange</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
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<td>1: BPM feedthrough</td>
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</tr>
<tr>
<td>2: C6 e-pickup</td>
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<tr>
<td>(at input coupler)</td>
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<tr>
<td>3: BPM feedthrough</td>
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<tr>
<td>2: C2/C8 e-pickup</td>
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<tr>
<td>(at input coupler)</td>
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<tr>
<td>1: C7 coupler flange</td>
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<td>Insulation to helium</td>
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<td>X</td>
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<td>2: C5 welding at helium tank</td>
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<td>C8 welding at bellow</td>
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<td>Insulation to input coupler</td>
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<td>1: C1 ceramic window</td>
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<td>1: C8 ceramic window</td>
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<td>Cool-down warm-up</td>
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</table>
Problems during assembly and testing

- Leaks in clean room
  - new assemblies without HPR
  - sealing with ‘sticky tape’ at M2 cavities and BPM/Valve connections in all modules

- Untested parts
  - Warm/cold coupler parts (schedule)
  - Feed-throughs
  - HOM pickups changed, more difficult adjustment

- Parts not fitting together
  - N-type HOM connector inhibits mounting of the tuner
  - DESY II type couplers to NbTi flanges -> special seals
  - Tuning system at the end of the module
  - Split flanges to beam tubes (M2)
Problems during assembly and testing

• Difficulties in Adjustment
  – Cavity-to-cavity in clean room
  – Cryostat to cold mass -> Coupler antenna contact to niobium port
  – Tilt of Quad lead to bellow damage (C8 in M1*)

• Complicated assemblies
  – Coupler
    • assembly M1*
    • disassembly M3
    • Position of couplers difficult to predict warm/cold position
  – Gripping of threats /Material problems
    • Coupler supports could only partly be mounted
    • Cavity to cavity bellow supports
    • Traces of AlMg3 gaskets on steel flanges
Problems during assembly and testing

• Shorts on cables (4 x)
• Problems with infrastructure
  – Cleanroom air condition (M2, M5)
• Accidents
  – C8 in M2 in HPR
• Several transports (M1*)
• Long storage (M1*)
• Lack of time for processing RF components