1 Nuclear Fusion (FUSION): Plasma Heating Systems -Microwave Plasma Heating & Current Drive Systems-

Contact: Dr. Gerd Gantenbein

The Department for High Power Microwave Technologies is focusing on the research and development of high power RF sources (gyrotrons) and related components for electron cyclotron resonance heating and current drive (ECRH&CD) of magnetically confined nuclear fusion plasmas.

In particular the following major activities have been carried out in 2017:

- Gyrotron Development for W7-X, targeting at 1.5 MW RF power at 140 GHz.
- Experimental study on further performance optimization of the European 1 MW, 170 GHz Hollow-Cavity Gyrotron Prototype for ITER.
- 2 MW, 170 GHz Longer Pulse Coaxial-Cavity Gyrotron Prototype, upgrade of the modular short pulse gyrotron with internal cooling systems.
- Gyrotron Development for DEMO, with the focus of efficiency enhancement by multi-staged depressed collectors.
- Developments on theory and numerical simulations of beam-wave interaction tools, electron beam-optics codes and quasi-optical systems.
- FULGOR: progress in the erection of the new gyrotron test stand
- Generation of ultrashort pulses using advanced gyro-TWT design.

1.1 Gyrotron Development for W7-X

Contact: Dr. Konstantinos Avramidis

Since the very beginning of the operation of the stellarator Wendelstein 7-X (W7-X), the Electron Cyclotron Resonance Heating (ECRH) system, consisting of ten 1 MW, 140 GHz gyrotrons, has exhibited a remarkable performance. The available EC heating and current drive power in the plasma ranges from 7 to 9 MW, that is, W7-X is using the world's largest ECRH system today. The possibility of even higher ECRH power in the future is under consideration. Motivated by this, studies towards an upgraded 1.5 MW, 140 GHz gyrotron design were initiated, which showed that the most promising development path, with respect to risk and cost, would be the upgrade of the existing $TE_{28,8}$-mode gyrotron of W7-X, in order to operate in the $TE_{28,10}$ mode.

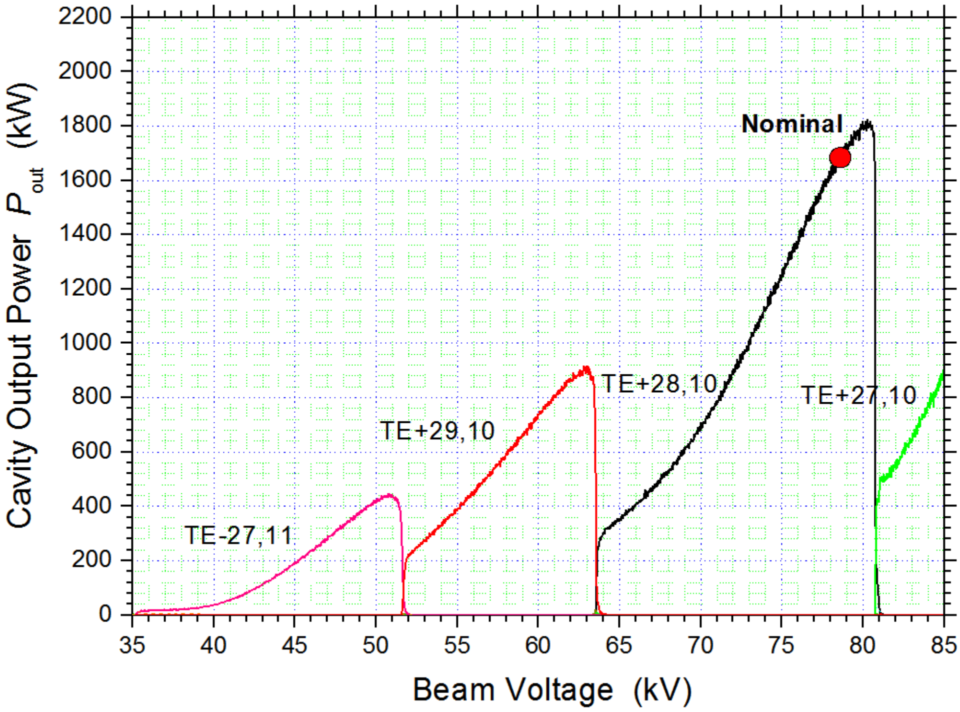

Fig. 1.1.1: Simulation of the TE28,10-mode gyrotron start-up considering 83 competing modes.

In this period, an optimised design for the cavity and non-linear uptaper of the $TE_{28,10}$-mode gyrotron has been obtained, which fulfils the specifications and requires the smallest changes with respect to the existing gyrotron layout. Beam-wave interaction simulations, taking into account realistic spreads in the electron beam parameters, verified the cavity & uptaper performance. An example is given in Fig. 1.1.1, where the $TE_{28,10}$ mode generates 1.7 MW in the cavity at nominal operation (78.5 kV, 56 A, 5.55 T) with an estimated total efficiency of 35 % without depressed collector. A first assessment of the necessary modifications of the rest of the gyrotron components has also been made.

In support to the investigations on the W7-X gyrotron upgrade, the components of a $TE_{28,10}$ mode generator for low-power tests of the quasi-optical mode converter system of the gyrotron have been designed and manufactured (Fig. 1.1.2). The mode generator has been assembled and experimental results are expected in 2018.

Fig. 1.1.2: Components for the $TE_{28,10}$ mode generator: cavity with coaxial insert (left) and taper (right).

The possibility of MW-class operation of the upgraded gyrotron at the additional frequency of 175 GHz for Collective Thomson Scattering diagnostics has been also studied. Initial results showed that the designed cavity could operate in the $TE_{36,12}$ mode and yield 1.2 MW at 175.8 GHz at the operating point of 78 kV, 55 A, 7.0 T with 26 % total efficiency without depressed collector.

1.2 Gyrotron Development for ITER

Contact: Dr. Tomasz Rzesnicki

1.2.1 Experimental study on further performance optimization of the European 1 MW, 170 GHz hollow-cavity gyrotron prototype.

The EU 1 MW, 170 GHz gyrotron with hollow cylindrical cavity has been designed within the European GYrotron Consortium (EGYC) in collaboration with the industrial partner Thales Electron Devices (TED) and under the coordination of Fusion for Energy (F4E). The experimental verification of the Short-Pulse (SP) gyrotron prototype was successfully completed in 2015. In order to investigate the further optimization of the gyrotron performance, additional tests with the modified SP prototype have started. The activities are focused on the increasing of the total efficiency towards 50 % (ITER requirement) in depressed collector operation. The saturation of the gyrotron efficiency at higher retarding voltages, which was observed during the experiments with the CW tube was theoretically predicted by simulations of the overall gyrotron geometry and is related to the reflection of electrons in the region of the mirror-box, due to a significant drop of the electron kinetic energy caused by the voltage depression of the spent beam space-charge, which defines the limits of the applicable maximum body voltage, before reflection of electrons begins. That effect is mainly governed by the geometrical arrangement of the gyrotron inside the mirror box. In order to perform a study of this effect different configuration setups, based on additional structures i.e. metallic pipes or optimized potential elevating structure (Fig. 1.2.1) installed inside the mirrorbox, have been prepared for the tests. The achieved results have been compared with an optimal depression voltage arrangement where the retarding voltage was set on the gyrotron by using of the ceramic-isolated collector of the 2 MW, 170 GHz coaxial-cavity short-pulse gyrotron prototype that is available at KIT.

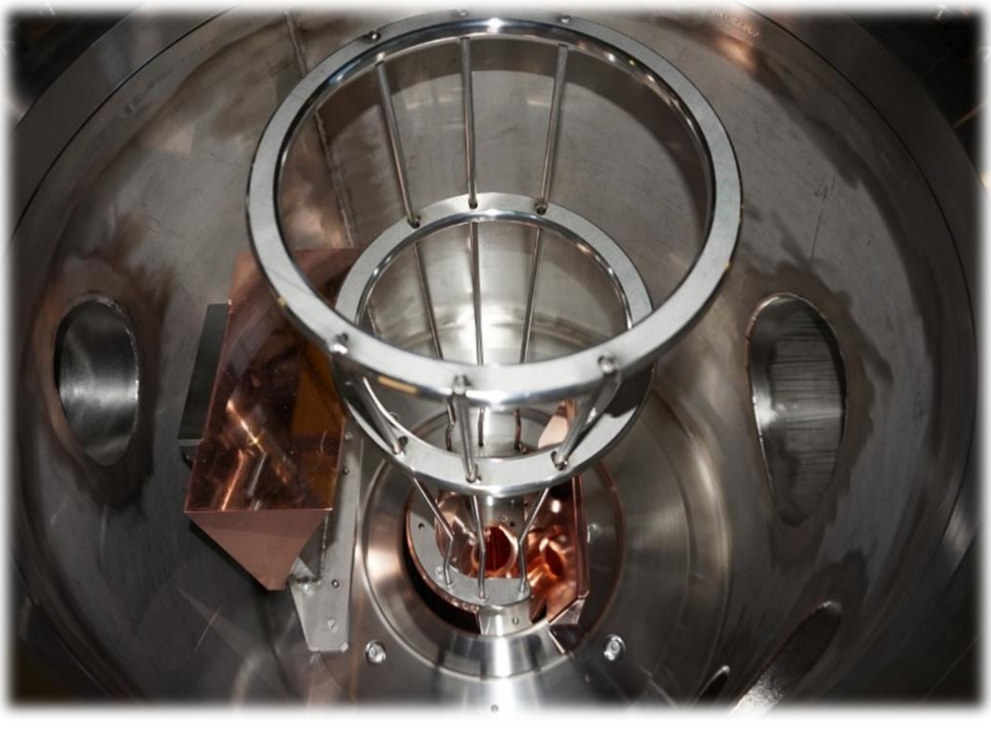

Fig. 1.2.1: Potential elevating structure.

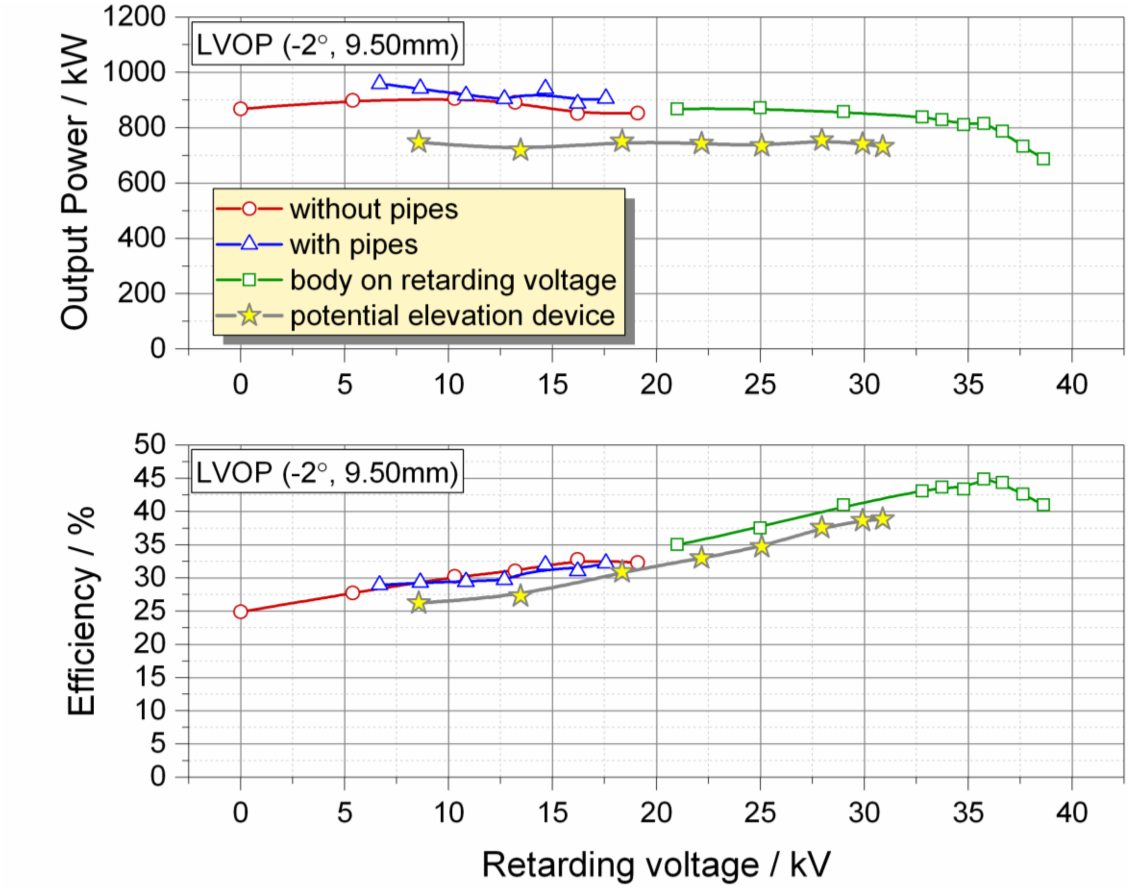

Fig. 1.2.2: RF power and total efficiency vs. retarding voltage obtained experimentally with different gyrotron configurations. *(bottom).*

Fig. 1.2.2 presents the generated RF power and the corresponding efficiency for the four different gyrotron configurations: (a) original “basic” setup in 2015 (red line), (b) cooling pipes mock-up installed in the mirror box and set on High Voltage (HV) (blue line), (c) optimized potential elevating structure (grey line) and (d) complete mirror-box set on HV (green line). In all cases the operating parameters are close to the nominal ones. As already predicted theoretically, the best results have been achieved by placing of the retarding potential on the gyrotron body. It resulted in an increase of the total gyrotron efficiency from 34 % to close to 45 % (retarding potential on the body).

Preliminary tests of the first version of the potential elevating structure confirmed a significant increase of the efficiency close to 40 %, limited by the maximal possible value of the applicable body voltage (~32 kV), due to vacuum issues. The gyrotron performance equipped with the potential elevating structure is expected to be similar to the configuration with the HV on the gyrotron body, being possibly a reasonable alternative solution for hollow cavity gyrotrons in the future. Final validation of the structure at better gyrotron conditions are planned for 2018.

1.3 Gyrotron Developments for future DEMO

1.3.1 Developments in frame of EUROfusion

Contact: Dr. Konstantinos Avramidis

The R&D towards a gyrotron that will meet the requirements posed by the envisaged Electron Cyclotron Heating and Current Drive system for DEMO is, at the largest part, performed within the Work Package Heating and Current Drive (WPHCD) of EUROfusion. The studies are in line with the European Fusion Roadmap towards a demonstration power plant. Gyrotron R&D is a necessary step to bridge the gap between today's state-of-the-art gyrotrons and future gyrotrons for DEMO. The EU DEMO1 baseline 2015 poses significant challenges on the gyrotron. These are the need for dual, high-frequency operation (170/204 GHz) and/or fast frequency step-tunability, as well as the requirements for higher power (2 MW), higher overall efficiency (≥60 %), and a higher level of Reliability-Availability-Maintainability-Inspectability (RAMI) in line with that of a power plant. To keep the gyrotron R&D relevant with respect to possible baseline changes and to alternative reactor configurations towards a future power plant, efficient MW-class gyrotron operation at higher (~240 GHz) frequencies is also considered in parallel.

The advanced concept of the coaxial gyrotron has been selected as being the most promising, compared to the conventional hollow-cavity gyrotron, towards the higher power and frequency target, since the enhanced mode selectivity of coaxial cavities permits stable operation at very high-order modes, which are compatible with large dimensions of the gyrotron cavity. The 170 GHz, 2 MW short-pulse coaxial gyrotron at KIT has already exhibited excellent performance at ms pulses. The next step for coaxial gyrotron technology towards DEMO is to prove experimentally its capability for long-pulse operation, especially with respect to the cooling and alignment of the coaxial insert. To this end, the coaxial gyrotron has been upgraded in this period with new, water-cooled components and experiments targeting at 100 ms pulses are expected in early 2018. The gyrotron is shown in Fig. 1.3.1. Supportive multi-physics numerical investigations on the cooling of the coaxial insert have also been performed. It was predicted that the cooling is compatible with continuous-wave operation. According to the calculations, a heat flux to the insert of up to 0.39 kW/cm2 and an insert misalignment of up to 0.2 mm can be acceptable. This gives a large margin with respect to the expected values (i.e. heat flux < 0.15 kW/cm2, misalignment < 0.1 mm).

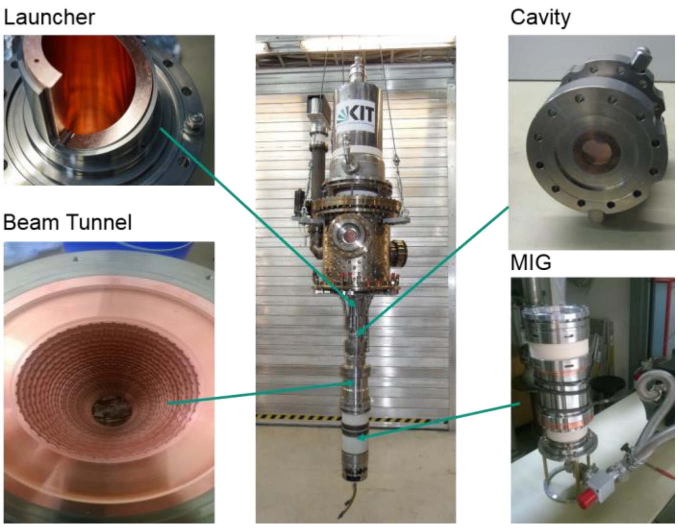

Fig. 1.3.1: The assembled longer-pulse 2 MW coaxial gyrotron and its components.

To keep the development path towards the DEMO gyrotron as fast and cost-effective as possible, the design of a 2 MW, 170/204 GHz coaxial gyrotron has been initiated using the existing 170 GHz, 2 MW coaxial gyrotron as a starting point. A preliminary assessment showed that a good performance can already be achieved with relatively minor modifications of the existing gyrotron. MW-class operation at 237 GHz seems also possible. The investigations focused on the gyrotron cavity and its calculated performance is summarised in Table 1.3.1. The Table includes results for the existing cavity of the coaxial gyrotron as well as for a proposed, slightly modified coaxial cavity with a shorter midsection, which achieves a more balanced performance at the three different frequencies. In parallel, the theoretical studies on 2 MW, ~240 GHz gyrotrons operating at very-high-order modes have been continued, focusing on the tolerance of misalignments and on start-up scenarios using triode-type electron guns to increase the mode selectivity.

Cavity	Existing coaxial cavity			Modified coaxial cavity		
Frequency [GHz]	170.00	204.14	237.17	170.04	204.16	237.18
Operating mode	$TE_{34,19}$	$TE_{40,23}$	$TE_{48,26}$	$TE_{34,19}$	$TE_{40,23}$	$TE_{48,26}$
Beam energy [keV]	90	80.7	60	92.8	88	78
Beam current [A]	75	70	60	75	75	70
Cavity power [MW]	2.25	1.8	1.04	2.5	2.2	1.63
Interaction efficiency [%]	34.9	33.0	30.2	36.7	33.4	30.2

Table 1.3.1: Simulated performance of triple-frequency operation of the coaxial gyrotron cavity.

The target of ≥ 60 % efficiency for the DEMO gyrotron implies the development of advanced, Multi-Stage Depressed Collectors (MDC) to increase the energy recuperation from the spent electron beam. Given that in the gyrotron the electrons are guided by a strong magnetic field to the collector, the required separation of electrons according to their energy, necessary for MDC operation, is quite challenging. Extensive investigations on different MDC concepts culminated in a very promising configuration, based on the E×B drift concept and adopting helical electrodes (Fig. 1.3.2). Extensive Particle-In-Cell simulations of a two-stage collector showed very good handling of secondary electrons, which is one of the major issues in MDCs, and demonstrated a collector efficiency of 77 %, resulting in an overall gyrotron efficiency of 63 %. Excellent tolerance in electron beam misalignments and stray magnetic fields was also demonstrated. The latter is shown in Fig. 1.3.2.

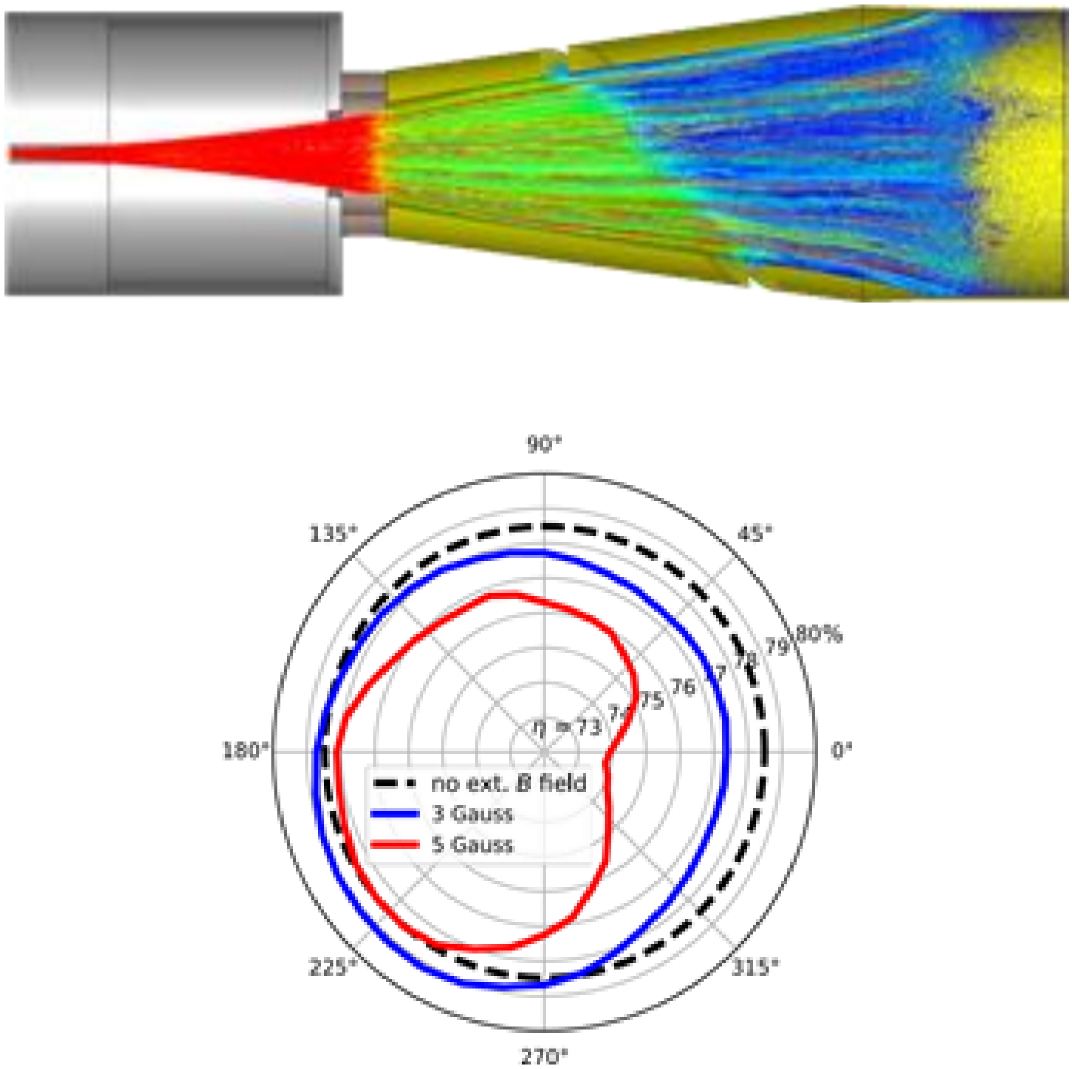

Fig. 1.3.2: Top: a two-stage E×B helical MDC with electron trajectories colour-coded according to kinetic energy. Bottom: dependence of the collector efficiency η on the direction of a perturbing magnetic field perpendicular to the collector axis.

The required high RAMI level of a DEMO gyrotron calls for further optimisation of all critical gyrotron components in terms of reliability and robustness. In this frame, investigations on advanced cooling methods of the gyrotron cavity, including micro-channel cooling and spray cooling have been initiated. More important, a new advanced triode-type Magnetron Injection Gun (MIG) has been procured for the existing coaxial gyrotron by Thales Electron Devices (TED, Vélizy-Villacoublay, France) and will be installed in the gyrotron in 2018. The gun is designed to be free of electron trapping mechanisms, i.e. compatible with long-pulse operation and is manufactured with coated emitter edges to minimise the influence of manufacturing tolerances and edge effects on the electron beam quality (Fig. 1.3.3). This is the first time in Europe that this technology is used for gyrotrons.

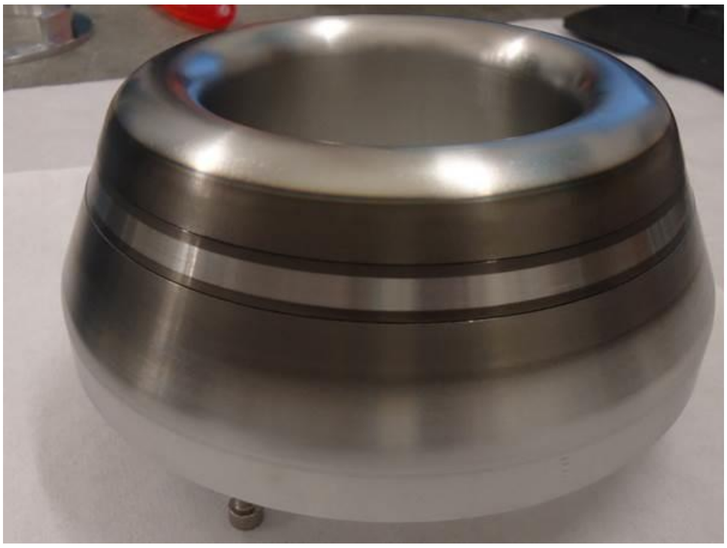

Fig. 1.3.3: MIG mock-up cathode with coated emitter edges.

1.3.2 2 MW, 170 GHz longer pulse coaxial-cavity gyrotron prototype.

Contact: Dr. Tomasz Rzesnicki

For fusion power plants that shall generate significant electric power such as DEMO the required RF power, efficiency, and operating frequency of gyrotrons needs to be further improved. A minimum RF output power of 2 MW at continuous wave (CW) and at operating frequencies up to 240 GHz are currently required. In order to satisfy those requirements, KIT is working on advanced gyrotron concepts, particularly on the coaxial-cavity gyrotron technology. Experiments at KIT demonstrated its superior performance by showing an RF output power above 2.2 MW in short pulses (ms-range) at an operating frequency of 170 GHz. In comparison to the classic hollow-cavity gyrotron technology widely used in todays fusion gyrotrons the coaxial-cavity gyrotron technology offers reduced voltage depression and mode competition. That allows an operation at very high-order operating modes, which leads to a significant higher RF output power. At KIT a modular-type of 2 MW 170 GHz coaxial-cavity short-pulse (ms) pre-prototype gyrotron operating at very short pulses up to a few milliseconds has been used to verify the superior performance of the coaxial-cavity gyrotron technology so far. A first industrial 170 GHz 2 MW coaxial-cavity gyrotron prototype operating at long pulses was built and was tested for ITER in 2012. In favor of the ITER EU 1 MW gyrotron development that 2 MW development was put on hold for ITER. Nevertheless, in frame of EUROfusion and supported by F4E the coaxial-cavity development continues at KIT. Currently, the main focus of KIT is to verify the performance of the coaxial-cavity gyrotron at longer pulses. As a first step towards a coaxial-cavity gyrotron operating at CW, a new modular gyrotron prototype was constructed, with the goal to extend the pulse lengths up to 1 s. This tube allows the verification of the gyrotron performance at extended pulse duration and validation of all operating parameters relevant for further CW operation. Furthermore, the pre-validation of the critical gyrotron components at longer-pulse regime is possible, in particular the behavior of the inner conductor, during heating up. Hence, the main issue for the construction of the new propotype gyrotron was the introduction of a reliable cooling systems for the beam tunnel, cavity, launcher, quasi optical mirror system, CVD diamond output window and the collector. Due to the presence of an independent cooling system for each component, monitoring of the internal losses in each gyrotron component and of the final energy balance of the tube during longer-pulse operation is possible. A very big advantage of this longer-pulse gyrotron is the modular construction. It allows an easy implementation and testing of new subcomponents with advanced water cooling systems, material compositions and geometries. The assembled longer-pulse gyrotron, installed in the superconducting (SC) magnet, ready for the first operation is shown in Fig. 1.3.4.

A bake-out procedure of the complete tube has been applied resulting in significantly better vacuum conditions. Experimental results will be expected in 2018.

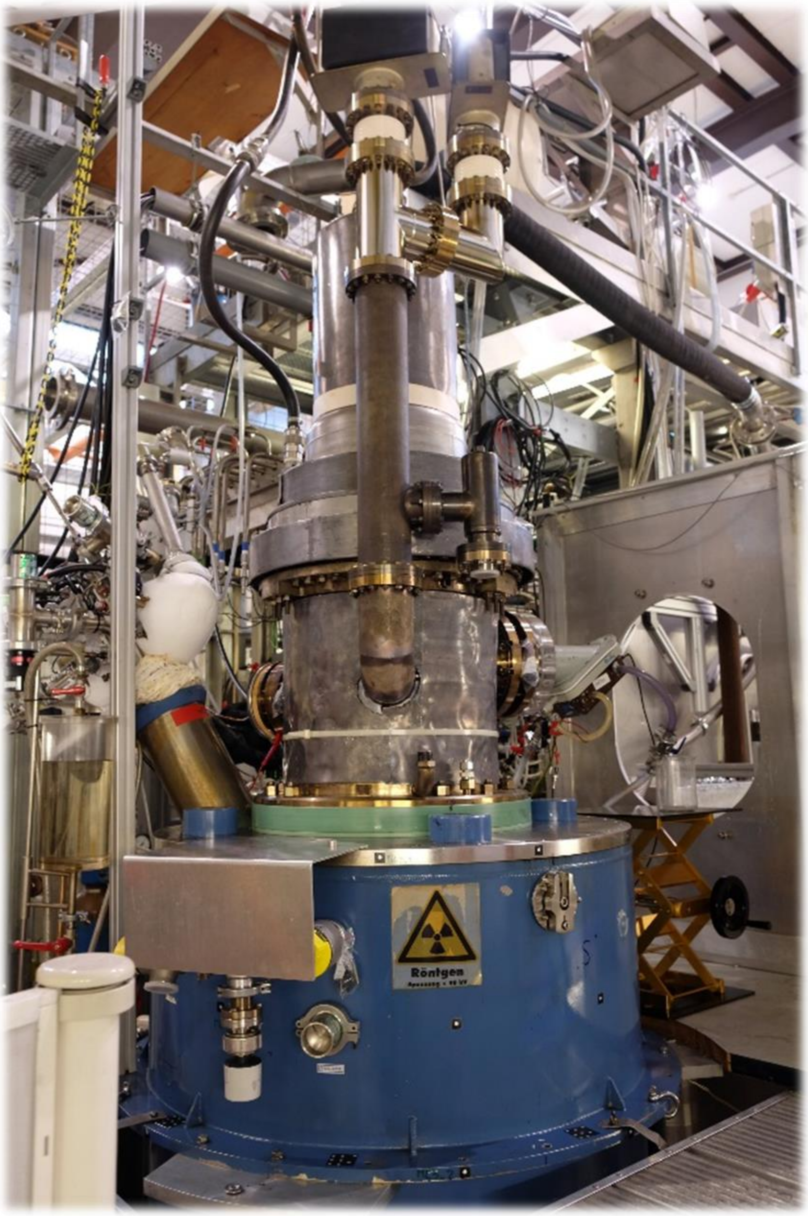

Fig. 1.3.4: The KIT 2 MW coaxial-cavity longer pulse gyrotron in the superconducting magnet.

1.4 Developments on theory and numerical simulations

Contact: Dr. Stefan Illy

1.4.1 Cavity simulation and beam-wave interaction tools

A multi-physics numerical procedure has been established, in collaboration with the Polytechnic University of Turin, which models the influence of the thermal expansion of the gyrotron cavity on the expected gyrotron performance. It is an iterative simulation method, which involves electrodynamic, thermal-hydraulic, and thermo-mechanical simulations. For the electrodynamic simulations, the in-house code-package EURIDICE for gyrotron interaction calculations and cavity design is used. A new module for addressing different models for the temperature dependence of the cavity wall conductivity has been developed and included in EURIDICE. Four different models were implemented, based on the ITER Material Properties Handbook as well as other sources. The materials under consideration are Glidcop and pure copper, which are the ones used in gyrotron cavities. The multi-physics numerical procedure has been used to simulate the European 170 GHz, 1 MW continuous-wave prototype gyrotron for ITER, considering both the existing cavity cooling system (see Fig. 1.4.1) and proposals for an improved cooling system. The longer-pulse 170 GHz, 2 MW coaxial gyrotron at KIT was also simulated using this procedure.

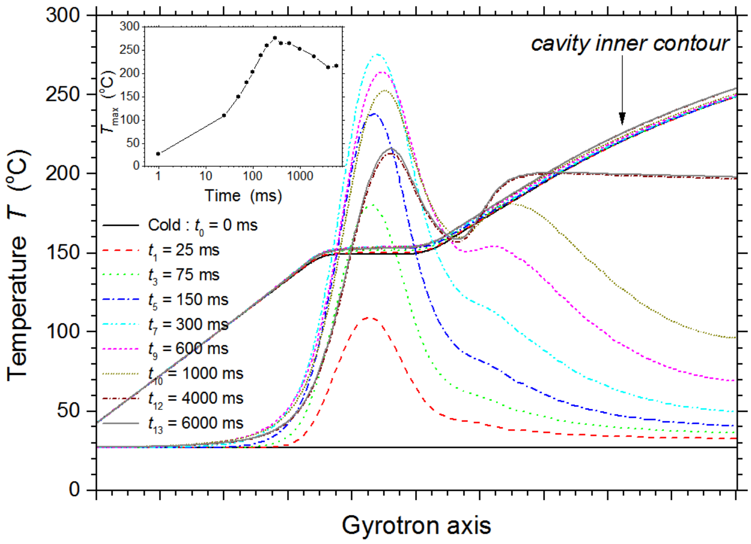

Fig. 1.4.1: Temperature profile along the inner contour of the cavity of the EU gyrotron for ITER, as obtained by transient multi-physics modelling. The change of the inner contour due to the thermal expansion is also shown. The inset shows the evolution of the maximum temperature with time.

Advances in the modeling of the beam-wave interaction in gyrotrons using 3D, full-wave, Particle-In-Cell (PIC) codes have been made. Technical details, theoretical input, and numerical results from the in-house code-package EURIDICE have been provided to support PIC simulations of test cases as well as real gyrotrons using CST Particle Studio, the code PICLas from the University of Stuttgart, and VORPAL. In all simulated cases a good agreement between the codes has been reached. This has been a significant step in increasing the confidence in 3D, full-wave PIC codes with respect to their capability of reliable simulations of the gyrotron interaction.

1.4.2 Improvements of the electron beam-optics codes

ESRAY

The beam-optics toolbox ESRAY has been extended to allow a smoother simulation of the so-called vertical sweeping of gyrotron collectors. In this case strong eddy currents are induced in the relatively thick cylindrical copper wall of the collector. Since the magnetic field calculation tool of ESRAY can not handle eddy currents, this part of the simulation has been shifted to the freely available FEMM simulation program. ESRAY has been extended to allow better interaction with FEMM with regard to the definition of coil geometries, materials and data exchange between both programs. This now allows the definition of arbitrary waveforms for the sweeping current based on a Fourier series expansion of the current and the corresponding periodic magnetic field distribution in the collector. In the frame of a Bachelor thesis from Jackowski (2017), a conceptual study has been performed to show the possibility and benefits of vertical sweeping with advanced, optimized sweeping current waveforms. Fig. 1.4.2 illustrates the shape of such a waveform applied to a proposed coil for the relatively compact collector of the 2 MW, 170 GHz coaxial cavity "longer pulse" gyrotron. Fig. 1.4.3 shows the corresponding load profile on the collector wall, indicating that the critical peaks of the wall loading will be reduced by nearly a factor of two compared to conventional sweeping with a sinusoidal waveform.

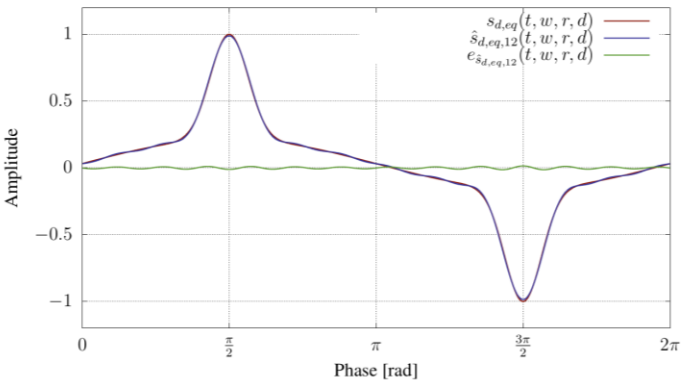

Fig. 1.4.2: Proposed current waveform for the enhanced sweeping concept, indicating the shape of the pre-defined current, it's approximation by a Fourier series and the (negligible) corresponding difference *e*.

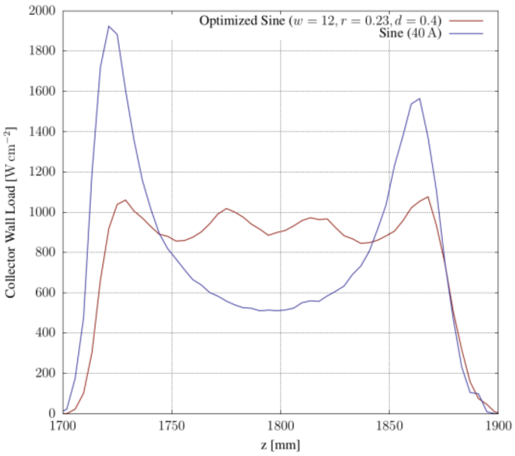

Fig. 1.4.3: Obtained averaged power density for the case of sinusoidal sweeping (blue) and sweeping with the advanced current waveform (red).

ARIADNE

The tracking code ARIADNE has been extended to allow convergence at the presence of trapped electrons. This is achieved by the definition of two relaxation factors: (i) the first one for the electron beam space charge required for the Poisson solver, and (ii) the second one for the definition of the amplitude of the mode in the cavity. In particular, for the solution of Poisson equation not only the space charge of the beam at the last iteration is considered, but also the space charge of the previous iteration. The percentage of the space charge contribution of the previous iteration and the last one is defined by a user defined variable. Similar procedure is followed with the amplitude of the mode in the cavity. The amplitude of the mode in the cavity is defined by the energy losses of the beam electrons at the last iteration, but also the energy losses of the previous iteration. Similar to the space charge contribution, a user defined factor determines the percentage of the last and the previous iteration contributions on the cavity mode amplitude. Using this upgrade, it was possible to numerically investigate the behavior of the beam electrons in case of applying a high deceleration voltage at the collector which causes electron reflections. It was possible to estimate the reflected current and the drop of the generated power as a function of the decelerating voltage and to investigate the peculiar trajectories of the reflected electrons.

In addition, the distributed memory parallization scheme of ARIADNE has been upgraded to a hybrid scheme in order to get the advantages of the multi-core share memory nodes of modern clusters. In particular, the distributed memory parallelization scheme based on MPI was upgraded with an additional shared memory scheme based on OpenMP. The whole mesh is stored only once in each node of the cluster, while the calculation of the electron trajectories are distributed on all processes (cores) of the nodes. In this way, it is avoided the multiple storage of the mesh in the memory of the same node and provide us the possibility to significantly increase the mesh density and the number of electrons considered in simulations.

1.4.3 Simulation and design of quasi-optical components

TWLDO (Tools for Waveguide Launcher Design and Optimization)

The method used in the TWLDO code for the analysis of the field distribution on the launcher wall has been improved. In TWLDO code, the input field of launchers is defined as the field distribution on waveguide walls in the area $-\infty < z < 0$. In the numerical calculation, it is impossible to calculate the field distribution in the semi-unlimited input area ($-\infty < z < 0, z = 0$ means the entry of launcher), therefore the field distribution in the area $-7L < z < 0$ on waveguide walls is used to approximate the semi-unlimited input area, where L is the launcher length. In the case that the discontinuity point of the field distribution is far away from the launcher (at z=-7L), the influence of the discontinuity on the field distribution on the launcher wall (at z>=0) is quite small. In the modified TWLDO code, in order to depress the influence of the discontinuity, the input field f in the area $-7L < z < -6L$ is smoothly increased from 0 to the full cavity field f_c as following:

$$f = \begin{cases} f_c\left(\dfrac{1-\cos\left(\dfrac{(z+7L)\pi}{L}\right)}{2}\right) & -7L < z < -6L \\ f_c & -6L < z < 0 \end{cases}$$

The simulation results show that the influence of the discontinuity due to the limited calculation area has been depressed by this procedure.

A quasi-optical launcher for both co- and counter-rotating mode operating in the $TE_{32,9}$ mode at 170 GHz has been designed and tested using TWLDO code. The wall profile and the field distributions on the launcher wall are shown in Fig. 1.4.4. The position of the wave beams should be well arranged so that the both wave beams from $TE_{32,9}$ mode and $TE_{-32,9}$ mode could be located at the center of the launcher aperture.

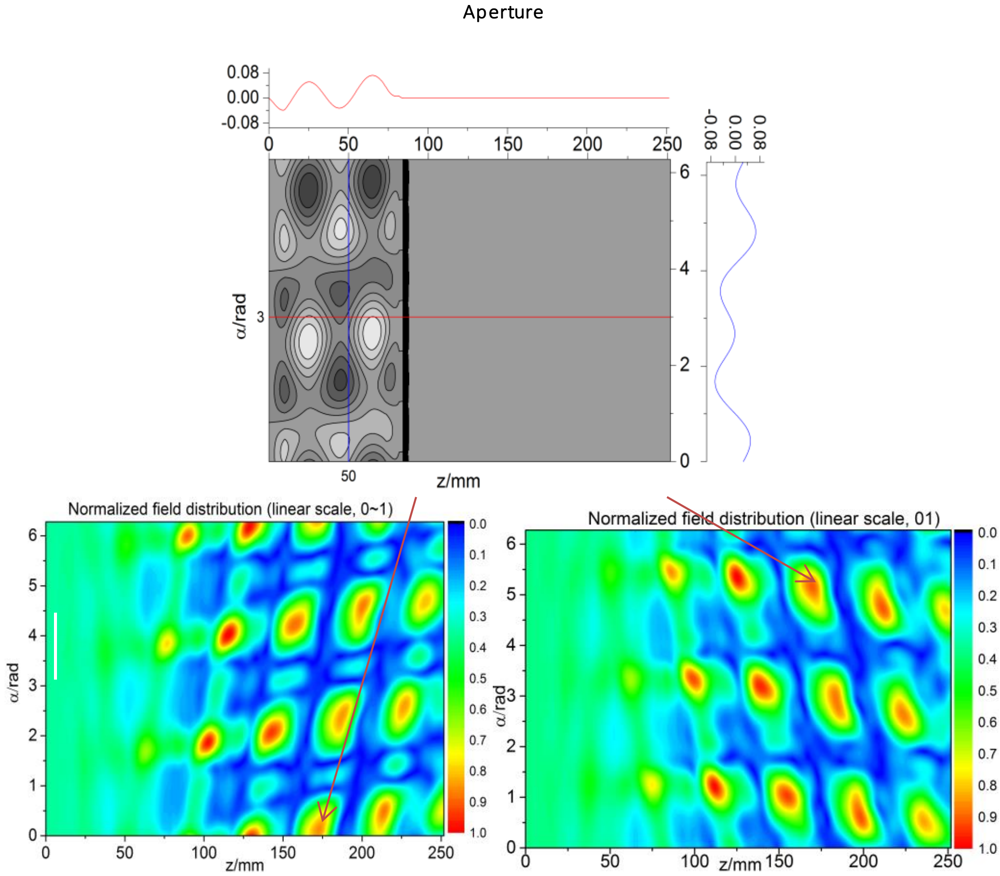

Fig. 1.4.4: The wall profile (left), the field distribution of the co-rotating mode (middle) and the counter-rotation mode (right).

KarLESSS (Karlsruhe Large Electric System Simulation Suite)

An advanced computer code (KarLESSS) [Ma17] for the full-wave simulation of quasi-optical systems in high-power gyrotrons is under development. The simulation program solves the electric-field integral equation with the method of moments. For an acceleration of the simulations, advanced methods as high order basis functions, high order meshes and compression algorithms based on the adaptive cross approximation (ACA) are used. In 2017, optimized versions of the ACA were implemented (ACA-SVD and SPACA). The so called ACA-SVD algorithm combines the ACA with an additional singular-value-compression to reduce the required memory during a simulation. The SPACA introduces a sub-sampling and a tree-structure of the basis functions to reduce the required calculation time and memory of the normal ACA. With the SPACA the favorable scaling of $N*\log(N)$ could be reached for the simulation of quasi-optical systems. In addition, an own preconditioner-algorithm, specialized for the ACA and its optimized versions was developed. With the developed preconditioner the convergence of the FGMRES algorithm, used for the solution of the system of linear equations, is effectively reduced.

1.5 FULGOR (Fusion Long-Pulse Gyrotron Laboratory)

Contact: Dr. Gerd Gantenbein

The existing gyrotron test facility at KIT, which had been designed and built more than 30 years ago, plays a worldwide leading role in the development of high-power gyrotrons for nuclear fusion applications. This facility offered the unique opportunity to develop and test the first CW high power series gyrotrons for the stellarator W7-X in collaboration with IPP and Thales Electron Devices as the industrial partner.

The target parameters of the new gyrotron test facility are well beyond the capabilities of the existing one. The new teststand will strongly support KIT's leading role in the development of advanced gyrotrons. It will help to answer the questions regarding the technical limits and new physical designs for future high-power microwave tubes. The key parameters of FULGOR will be:

- Full CW operation with up to 10 MW electrical power (corresponding to >= 4 MW RF power, assuming an efficiency of the gyrotron >= 40%)
- Support of advanced energy recovery concepts, e.g. multi-stage depressed collector (MSDC)
- Super conducting magnet with a flux density of up to 10.5 T

The high voltage power supply (HVPS) will support an operating voltage of up to 130 kV with up to 120 A beam current in short pulse operation and 90 kV / 120 A in continues wave regime. The superconducting magnet will allow operation of gyrotrons at frequencies well above 200 GHz (~ 240 GHz). Other significant components of the teststand are: cooling system, control electronics and interlock system, RF diagnostics including high-power RF absorber loads.

The capabilities of FULGOR will enable the development and CW tests of gyrotrons for future fusion machines like ITER and DEMO. Fig. 1.5.1 shows a simplified CAD view of the complete FULGOR system.

Substantial progress has been achieved in the planning, procurement and installation of major systems of the new teststand.

High Voltage Power Supply (HVPS): All EPSM power modules for CW operation (84 in total) have been tested (at AMPEGON), delivered and installed at KIT side. First tests of this system show very good results in agreement with the specifications. All modules of the pulsed power supply (PPS) (40 in total) for up to 5 ms operation have been produced, delivered and installed. A first phase of commissioning has been completed end of 2017, final acceptance will be in Q2/2018. Discussions with industry on a body power supply, necessary for operation of the gyrotron with energy recovery of the spent electron beam, have been started. The specifications have been fixed and several offers have been evaluated. The start of the procurement is expected for early 2018.

Cooling system: The cooling system is designed for full 10 MW CW operation. The final acceptance of the complete cooling system has been performed in 2017.

Control and data acquisition: The procurement and installation of components to control the teststand (HV power supply, cooling system, gyrotron control and diagnostic) has been continued.

Superconducting magnet: In 2017 the specifications of the magnet has been finalized, a call for tender has been launched and the system has been ordered. The key data of the magnet are: borehole diameter: 261

mm, max. B-field: 10.5 T, dipole coil system to optimize the electron beam position in the gyrotron, cryogen-free. The delivery of the system is scheduled for mid of 2019.

Microwave diagnostics: In cooperation with IGVP, University Stuttgart, the transmission system for the RF beam from the gyrotron window to the absorber load has been discussed. This system will include two matching mirrors and two polarisers which will allow broadband transmission. At IGVP the water cooled matching mirrors and a 2 MW absorber load have been ordered. The polarisers will be manufactured at KIT.

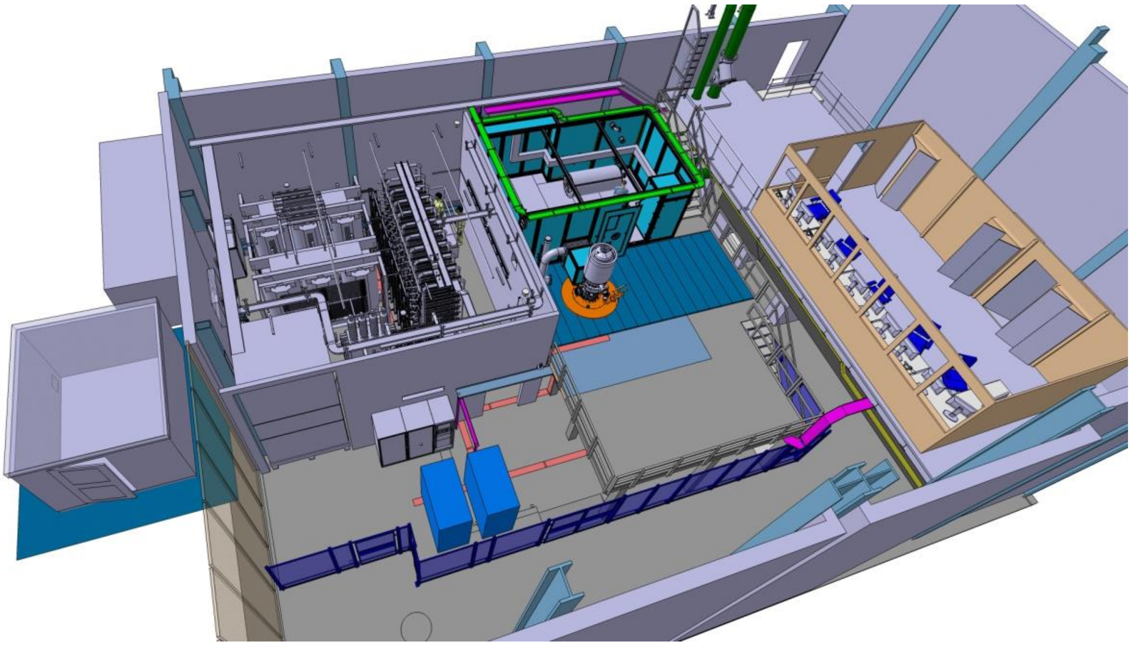

Fig. 1.5.1: FULGOR

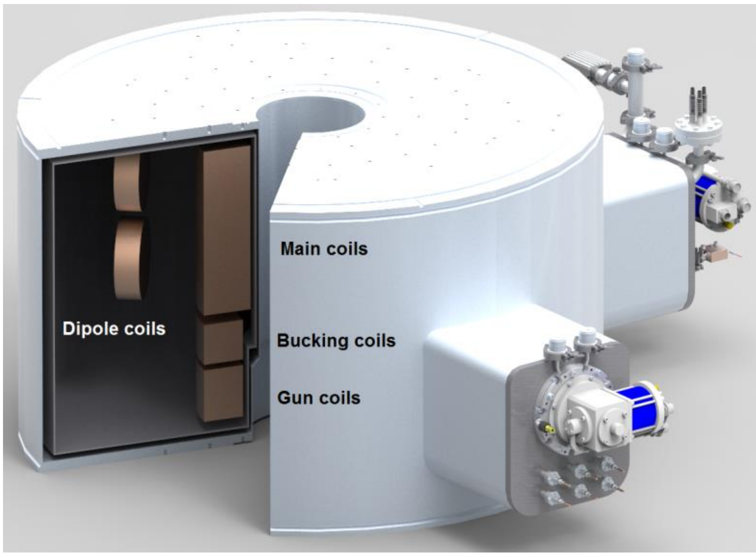

Fig. 1.5.2: NN: 10.5 T magnet with integrated dipole coils (Tesla Engineering Ltd).

1.6 Generation of ultrashort pulses using advanced gyro-TWT design

Contact: M.Sc. Alexander Marek

We study the generation of a periodic sequence of powerful short pulses in this project. The need for powerful pulsed sources of millimeter and sub-millimeter (sub-THz) radiation is motivated by a large number of fundamental problems and practical applications, including diagnostics of plasma, photochemistry, biophysics, new locating systems, and the spectroscopy of various media.

The pulses will be formed by a feedback loop of an amplifier and a nonlinear absorber (see Fig. 1.6.1). Both, amplifier and absorber will be realized as gyrotron-traveling-wave-tubes with helical corrugated interaction-region. The amplifier will run in a regime optimal for the maximal amplification of ultrashort pulses, while the absorber will run in the so called Kompfner dip regime, where low-energy pulses are absorbed while powerful pulses can pass the absorber without loss of energy.

For prove of concept, such a feedback loop should be first realized at a frequency of 35 GHz, but the final applications of the generated pulses will be in the sub-THz frequency range. Therefore, the key elements for a helically corrugated gyro-TWT with the frequency of 260 GHz, as well as a non-linear cyclotron absorber appropriate for this frequency range will be developed in parallel to the design of a feedback-loop at 35 GHz.

“Cold” simulations of the helical interaction region and of additional components as mirror systems for input/output systems were performed in a first step of the project [Ma17]. For this, our in-house developed full-wave simulation tool KarLESSS was used. Currently, “hot” simulations of the interaction are performed. Simulations of the separated amplifier and absorber components at 35 GHz are performed with the commercial tool CST [Gi17]. In parallel, we investigate in the usage of the advanced simulation program “PICLas”, developed by the Institute of Aerodynamics and Gas Dynamics at the University of Stuttgart. PICLas provides the great opportunity to verify the CST simulations and to allow a full PIC simulation of a coupled amplifier-absorber system.

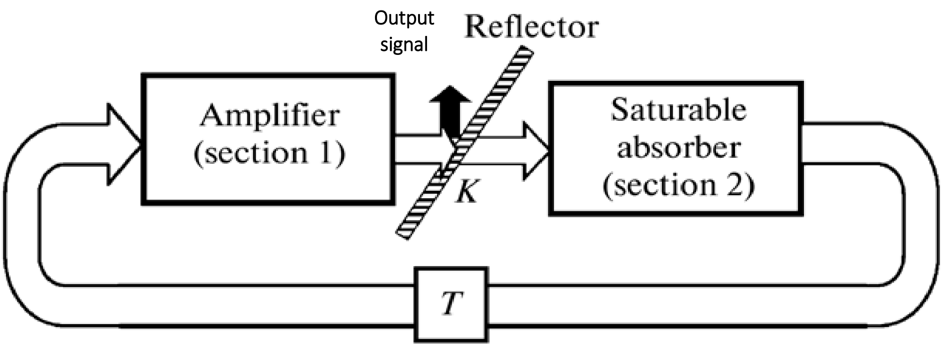

Fig. 1.6.1: Schematical view of concept, K: adjustable reflection factor, T: delay time of feedback coupling.

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Involved Staff:

KIT/IHM: K. Avramidis, J. Franck, M. Fuchs, **Dr. G. Gantenbein, Dr. S. Illy**, Dr. Z. Ioannidis, Prof. J. Jelonnek, Dr. J. Jin, P. Kalaria, Th. Kobarg, R. Lang, W. Leonhardt, M. Marschall, D. Mellein, A. Meier (KIT, IAM-AWP), Dr. I. Pagonakis, A. Papenfuß, S. Ruess (KIT CS), T. Ruess, **Dr. T. Rzesnicki**, Prof. Dr. Theo A. Scherer (KIT, IAM-AWP), M. Schmid, Dr. D. Strauss (KIT, IAW-AWP), Prof. M. Thumm, S. Wadle, J. Weggen, Ch. Wu, A. Zein, **IGVP (University of Stuttgart): Dr. W. Kasparek**, Dr. C. Lechte, R. Munk, Dr. B. Plaum, F. Remppel, H. Röhlinger, B. Roth, K.H. Schlüter, S. Wolf, A. Zeitler, **IPP (Greifswald/Garching):** B. Berndt, Dr. H. Braune, F. Hollmann, L. Jonitz, **Dr. H. Laqua**, Dr. S. Marsen, F. Noke, M. Preynas, F. Purps, A. Reintrog, T. Schulz, T. Stange, P. Uhren, M. Weißgerber, F. Wilde

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