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STATUS OF THE TURBINE-DRIVEN HV-GENERATOR FOR A RELATIVISTIC ELECTRON COOLER

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Abstract

Power generation by gas turbines at high potentials can become an alternative to insulating transformers or rotating shafts in electron coolers operating in the range of several MeV. Our main objective is to explore this technique for an application in a high energy cooling device at HESR. The status of the project, its potential advantages and the perspectives are discussed.

INTRODUCTION

Since electron cooling requires fulfilling the condition of equal ion and electron velocity it is mandatory to provide powerful electron beams in the MeV range for the upcoming HESR storage ring at the FAIR facility. The 2 MeV cooler from COSY [1] could be used but will only cover the lower energy range whereas antiproton cooling at the highest HESR-energies would require almost V=8 MV acceleration potential. One should keep in mind that cooling times can be significantly reduced if the beam is magnetized which will be necessary to counteract the heating effect of the internal target at the PANDA-experiment in HESR.

The longitudinal magnetization field is provided by a chain of solenoids which also has to cover the acceleration stage. The solenoids then sit at different potentials and need floating power supplies. Another supply is needed for the electron source/collector system at the HV-terminal. Therefore, several acceleration modules with an individual power supply are needed. If the number of modules is N, the potential difference between the stages is V/N. In a recent design study by Budker Institute for Nuclear Physics (BINP) it was suggested to choose V/N=0.6 MV, which allows using established HV-generators to maintain the voltage between the modules while keeping a pair of solenoids (for accelerated and decelerated beam respectively) at the potential of the module-deck. This arrangement of solenoids would still provide a reasonable field quality.

A number of N = 14 modules is needed to have some margin for an 8 MV device. The power consumption of a stage will be less than 3.5 kW. Including the terminal, a power ~ 50 kW on different HV potentials may be needed. The main purpose of the ongoing work is to demonstrate the reliability of the power generation approach and the scalability of the stages. Therefore, "HESR-prototype" HV-modules of 1:1 scale are being tested. An important question is the method of potential- free ("floating") power generation for which we use a special set-up at Helmholtz Institut Mainz (HIM). We address power generation in the next section and describe the status of HV-module experiments afterwards. Finally, the long-range plans will be explained in the "outlook"-section.

TURBINE APPROACH

There are several potential advantages of turbines as floating power generators compared to existing technologies like insulating transformers or generators driven by insulating rotating shafts which have powered devices at the ~5 MV level already [2,3].

We have demonstrated [4] that commercially available turbine-generators can provide the required power level for extended periods of time (>1000 h) without the need for maintenance. The turbo-generators are sold under the trade name "Green Energy Turbine" (GET) by the company DEPRAG [5] and deliver 5 kW per unit, so a single turbine can drive a HV-module. Investment costs are ~10 €/Watt (including the cost of the compressor) on the terminal and energy efficiency from wall plug to terminal is about 15% for our application. This can be considered as affordable as far as HESR operation is concerned.

The relatively low efficiency is to some extent caused by the pre-cooling of the compressed gas in our commercial compressor system (Fig. 1). The heat of the compressed gas is taken away by cooling water and is therefore lost. This happens *outside* the HV-device. Then the gas is sent to the HV-tank inlet at approximately room temperature. The expanding gas from the turbine *inside the HV-tank* is cooled since energy in form of electrical power is extracted from it. The electrical power is finally transformed again into heat by the loads. It is evident that the exhaust gas can be used to absorb this heat again. In our present set-up this is done by an air/liquid heat exchanger on the HV-deck. Stable thermal conditions at moderate temperature levels of the individual devices can be realized. A thermal management becomes thus possible, keeping temperatures inside the HV-tank at appropriate values. This feature is an advantage for the turbine, since other methods of power generation need additional cooling circuits with connection to heat exchangers at ground potential.

SET-UP AT HIM

Figure 1 shows the compressor with buffer tanks for the compressed gas. Copper tubes lead to the HV-module-inlet from where the gas is guided by a plastic tube towards the turbine. The compressor can drive three such turbines. In September 2018 BINP delivered the first HV-module to HIM, which carries a turbine on the HV-deck. The functionality was successfully tested albeit only at a voltage level of 60 kV due to the absence of a pressure vessel.

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Figure 1: Compressor system for driving up to three turbines at HIM. Size of compressor (grey box, upper right) is about 2,5*2*1m.

The HV-module (Fig. 2) is 3 meter in diameter in order to leave enough space for all components, in particular the turbines, heat exchangers, remote control, power supplies etc., as well as for the two acceleration channels with a sufficiently large insulation gap between the solenoids and the acceleration tubes. The solenoids consist of four sub-coils with suitable iron cores to achieve field flatness. The power consumption of each solenoid is 1300 Watts. Figure 3 a/b illustrates the dimensions of the solenoids. Due to the potential gradient along the acceleration tube and along the outer main construction frame of the module, the electrical field peaks at the inner as well as on the radial outer surface of the end of the solenoid, see indication in Fig. 3a. Under nominal operation conditions the maximum electrical field strength on the solenoid surface is about 4.2 MV/m [6,7]. This condition is the same for all solenoids in the different modules.

A pressure tank which can hold two modules plus the gun/collector stage has been ordered. Due to space limitations in the HIM experimental hall the inner diameter is restricted to 3.9 meter. The E-field strength on the inner cylinder in a configuration of concentric cylinders of inner and outer radii R_i, and R_o respectively is: $E=V/(R_i \ln(R_o/R_i))$. This function has a minimum at $R_o/R_i=e=2.71\ldots$. which means that for the present ratio $R_o/R_i \sim 1.3$ there is an enhancement of the field at the cylindrical surface by a factor 2 over the minimum achievable E for the present tank diameter. Note that this overshoot would only be 1.1 for a tank diameter of 6 m.

An additional field enhancement factor of < 1.59 [8] for the transition region between the cylindrical and the more or less spherical part in the terminal region should also be taken into account, In our intended operation with two modules at 1.2 MV we therefore estimate the maximum field strength to be <5MV/m. With pure N_2 as insulation gas, a pressure of about 6bar will be sufficient, though the insulating capabilities are lower compared to SF_6 by a factor ~2.5 – see the results by Hellborg [9] which were obtained at comparable voltages. This pressure is within the specifications of our tank. Using N_2 will avoid the administrative and technical complications associated with the use of SF_6.

The tank will be delivered in summer 2020 which will then allow testing the already existing module at the design voltage of 600 kV.

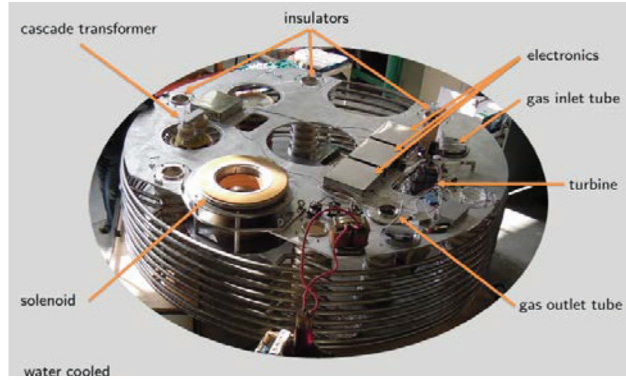

Figure 2: HV-module. Diameter of disc is 2.96 m, height of module is 0.7m. Only one solenoid is installed.

Negotiations for delivery of a second module between BINP and HIM are almost finalized. The operation of two stacked modules at 1.2 MV is intended which would give important information on the scalability of the approach towards higher voltages. This will also include the acceleration tubes with vacuum pumps operating at the module decks (Fig. 3b) which will establish improved vacuum conditions in the acceleration channel.

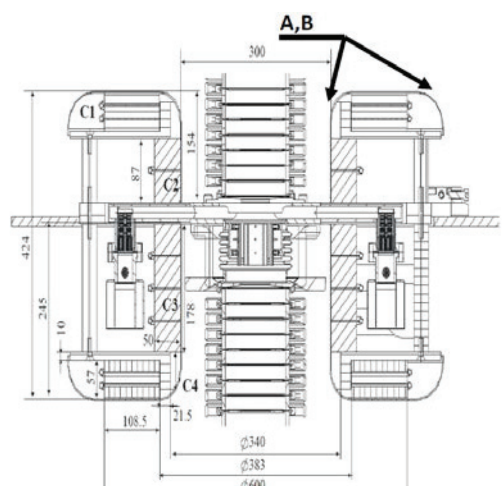

Figure 3a: Mounting of a solenoid on the module baseplate around the acceleration tube [6]. Dimensions in mm. Points A and B are regions of high field strength.

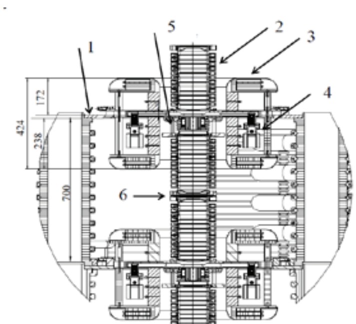

Figure 3b: Arrangement of two solenoids on different decks with 600kV acceleration in between [6]. 1: main construction frame, 2: acceleration tube 3: solenoids 4: vacuum pumps, 5 bellows and beam position monitor, 6: flange connection.

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OUTLOOK

Our next steps will be directed towards testing several turbines in parallel and to establish a regulation scheme to keep the system in a stable and safe operational state. Practical experience with the gas-distribution system and the heat exchangers inside the HV-tank has to be gained. Demonstration of the HV-capabilities of the turbine driven approach is the most important point, including the hitherto more or less untested gas-flow: gas has to be returned under a pressure of 1 bar to ground potential.

We believe that these experiments will extend over a timespan of several years, the end of which could coincide with the installation of the HESR at the FAIR site. The outcome of the demonstration experiments will allow a decision if the new technology is a suitable approach for high energy cooling at HESR.

In the long run it is also desirable to install a gun/collector system and a return path to be able to operate with electron beam as depicted in Fig. 4. Such an apparatus would come close to an operational electron-cooler. The realization of this device depends on the one hand on the availability of additional resources and on the hand it is not clear as of today if the additional effort will yield enough new insights to justify it.

However, we presently investigate if a similar extension of the apparatus could be used, e.g., to provide beam for experiments in the regime of Ultra-fast Electron Diffraction (UED). Due to the availability of ample electrical power on the terminal one can consider operation of power-demanding technologies such as radiofrequency bunchers which can provide very short bunches at the experimental site after acceleration with rather low energy spread. Moreover, the large size of the HV-modules allows installing also space consuming devices on the terminal, for which spin polarized electron sources are an example. Such sources usually require meters of space in in one direction due to the need for vacuum manipulators. This can be incorporated on the deck of the HV-module. By combination of both advantages one could do completely new experiments on fast processes in magnetic nanostructures by Spin-polarized ultra-fast electron diffraction (SUED).

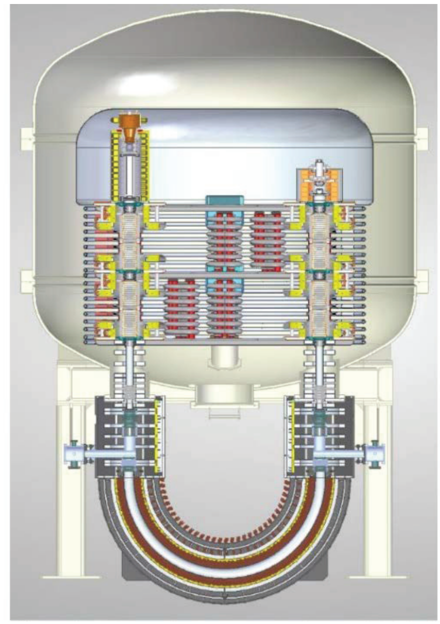

Figure 4: Possible configuration: Two modules at 1.2 MV with source, collector and return loop [7].

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