THE GREEN ENERGY TURBINE AS TURBO GENERATOR FOR POWERING THE HV-SOLENOIDS AT A RELATIVISTIC ELECTRON COOLER

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Abstract

One of the challenges in the development of a relativistic electron cooler is the powering of components, e.g. the HV-solenoids, which sit on different high potentials within a high voltage vessel and therefore need a floating power supply.

In this report we present the turbo generator "Green Energy Turbine" (GET), an assembly of a turbine and a generator, as a possible candidate for powering e.g. the HV-solenoids and give an overview over the future road map.

INTRODUCTION

In many experiments in hadron physics it is essential to keep the emittance constant, counteracting the emittance blow up e.g. due to scattering experiments. One way to prevent the emittance from increasing is the electron cooling technique [1], which will be used for example at the High Energy Storage Ring (HESR) at GSI/FAIR to permit high energy antiproton experiments [2]. The HESR has a circumference of 575 m and can operate in two modes, the "High Luminosity" (HL) and "High Resolution" (HR) mode. Some experimental demands are summarised in Table 1 [3].

Table 1: Experimental Demands of the HESR

	HL	HR
Momentum range	$1.5 - 15\ \frac{\mathrm{GeV}}{\mathrm{c}}$	$1.5 - 9\ \frac{\mathrm{GeV}}{\mathrm{c}}$
Peak luminositiy	$2 \cdot 10^{32}\ \frac{1}{\mathrm{cm}^2\mathrm{s}}$	$2 \cdot 10^{31}\ \frac{1}{\mathrm{cm}^2\mathrm{s}}$
Momentum resolution	$\frac{\Delta p}{p} = 10^{-4}$	$\frac{\Delta p}{p} = 10^{-5}$

To meet these requirements for the high resolution mode, magnetised electron cooling with a 4.5 MeV, 1 A electron beam is necessary. An intention for the HESR is an upgrade to the Electron Nucleon Collider (ENC). The ENC will allow experiments with polarised electrons and protons [4], which also need magnetised electron cooling. In that case, an 8 MeV, 3 A electron beam is needed. In order to solve critical technical issues, the Helmholtz-Institut Mainz (HIM) promotes collaborations with other Institutes such as Forschungszentrum Juelich (FZJ), Budker Institute of Nuclear Research Novosibirsk (BINP SB RAS), Russia and Lehrstuhl fuer Technische Thermodynamik und Transportprozesse (LTTT), University Bayreuth. One of the challenges is the powering of HV-solenoids, which are located on different electrical potentials inside a high voltage vessel, which is why they need a floating power supply.

Within a design study, BINP SB RAS has proposed two possibilities to build a power supply in a modular way. The first proposal is to use two cascade transformers per module. One cascade transformer powers 22 small HV-solenoids, the second one should generate the acceleration/deceleration voltage for the electron beam. The cascade transformers themselves are fed by a turbo generator, which is powered by a gas under high pressure that could be generated outside of the high voltage vessel. The second possibility is to use two large HV-solenoids per module, which are composed of four small coils. In this proposal, the HV-solenoids are powered directly by a turbo generator [5]. Both concepts have in common that they need a suitable turbo generator which delivers a power of 5 kW. A research for proper turbo generators has identified the Green Energy Turbine (GET) from the company DEPRAG as a potential candidate [6]. At HIM, two GET were bought and tested.

GREEN ENERGY TURBINE

The GET (Figure 1) is an assembly composed essentially of a turbine and a generator. Dry compressed air enters the

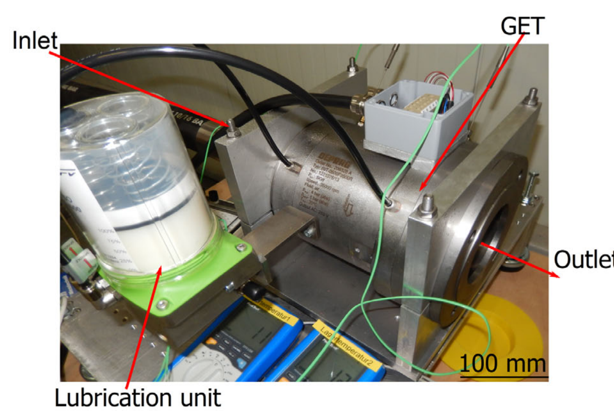

Figure 1: The turbo generator Green Energy Turbine (GET) with lubrication unit.

GET on the inlet side and is expanded through a nozzle. The resulting accelerated air drives a turbine, which in turn drives a generator. After the expansion, the air is diverted around the generator and leaves the GET on the outlet side at normal pressure. The generator is connected in delta configuration, which generates three-phase current. The turbine and the generator are supported by ball bearings, which was believed

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to need a small amount of fresh lubricant after 100 hours in regular operation [7].

Therefore, a lubrication unit which pumps 300 mm^3 lubricant into the bearings is mounted at the GET. The used lubricant is stored in special containers which are cleaned during maintenance, so that the contamination of the driving air is minimal. The GET itself should work the typical time for one production run at the HESR which is of the order of one year without maintenance. Further properties of the GET are listed in Table 2.

Table 2: Properties of the GET

Property	Value
Power	5 kW
Revolution speed	35000 min^{-1}
Pressure (in)	4 bar
Pressure (out)	1 bar
Mass Flow	4 $\frac{\text{m}^3}{\text{min}}$
Pressure condensation point	−20°C
Voltage phase to phase	263 V
Current	12 A
Norminal frequency	583 Hz

CHARACTERISATION OF THE GET

In order to characterise the GET, different test measurements with the turbo generator were done at HIM. The test set-up is shown in Figure 2. A buffer tank is filled by a

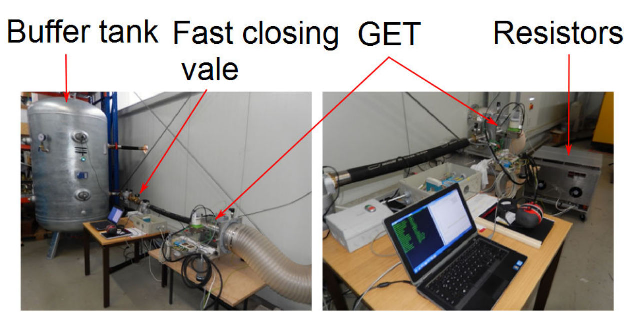

Figure 2: Test set-up at HIM for characterising the GET. Inside the buffer tanks heaters are installed for heating the pressurised air before it enters the turbo generator. The heaters are powered by the GET itself.

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compressor, which is outside of the hall and consumes a power of 40 kW to generate compressed air at 4 bar and an airflow of 4 $\frac{\text{m}^3}{\text{min}}$. In the buffer tank the air is heated to reduce the condensation (from the ambient air) due to the cooling of the air after the expansion, which also cools down the GET housing. The three-phase alternating current generated by the generator is rectified, as load resistors are used. To protect the GET, a fast closing valve is additionally installed, which immediately closes if the limits of the GET (e.g. $n_{\text{critical}} = 36000\ \text{min}^{-1}$, $I_{\text{critical}} = 16$ A) are exceeded.

Figure 3 shows the measurement of the DC power as function of the revolution speed and the input pressure for different loads.

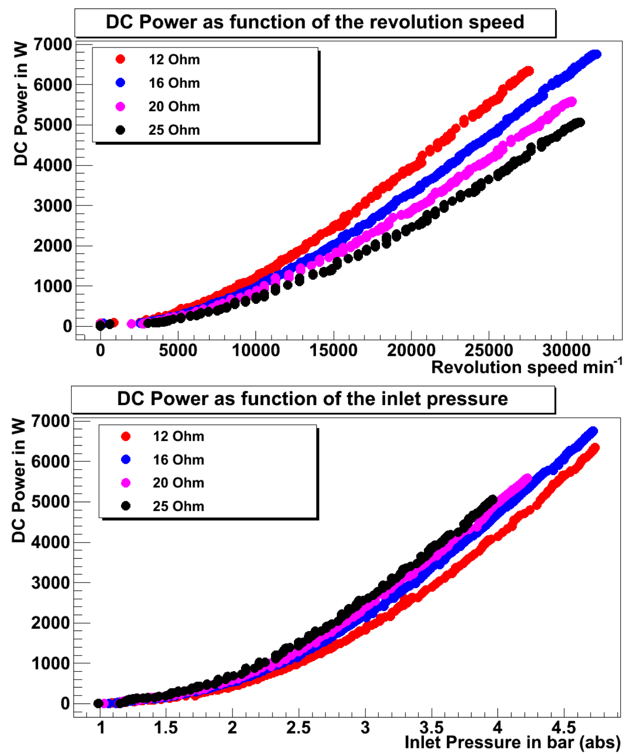

Figure 3: Measurement of the DC power as function of the revolution speed and the inlet pressure for different loads

The measurements show that it is possible to generate the needed power of 5 kW within the limits of the GET. The outlet temperature of the air for a load of 22.9 Ω is presented in Figure 4.

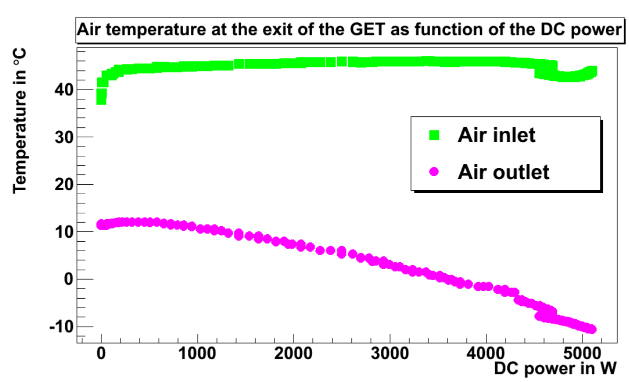

Figure 4: Air outlet temperature as function of the DC power for a load of 22.9 Ω. The measurement time was 2 min; the temperature drop of the air after the expansion is 53°C.

For a number of measurements with a load of 22.9 Ω a drop of the air temperature is in the order of (50 ± 5)°C and also cools down the GET housing.

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Another important point is the reliability of the turbo generator. For this reason, a long-term test over 1025 operation hours with a load of 22.9 Ω including many start and stop cycles was successfully carried out. The ball bearings were only lubricated at the beginning but not during the long-term test. During the test, the temperature change of the bearings and the excitation windings of the generator were recorded as well. The bearing temperature decreases in the order of 10°C due to cooling by the exhaust air, the temperature of the excitation windings increases in the range of 10 to 15°C.

FURTHER ROAD MAP

During its normal operation, the turbo generator will be inside a high pressure tank, which is filled with Sulphur hexafluoride at a pressure of 10 bar. This means that the turbo generator must be pressure-resistant at least until 10 bar. Therefore a modification of the test set-up is in preparation. The GET will be installed within a small pressure tank, which will be filled with dry nitrogen. Subsequently some of the characterisation measurements are repeated, e.g. the long-term test. But before the turbo generator can be installed in a pressure tank, it's necessary to modify the lubrication unit, because it is not pressure-resistant. The current lubrication is replaced by a pressure-resistant box as shown in Figure 5. If the tests with the modified turbo generator are successful, both GET are sent to BINP SB RAS to implement them in a test set-up for powering HV-solenoids, which will be sent and installed at HIM later [5].

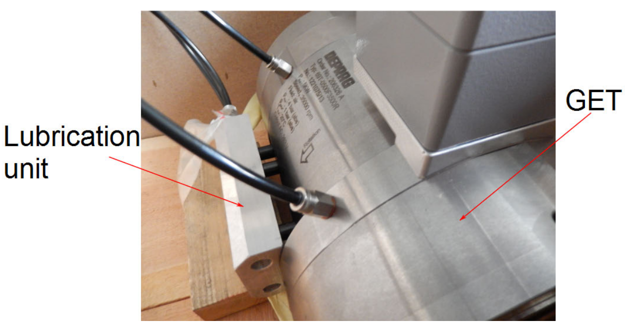

Figure 5: GET with modified pressure-resistant lubrication unit. The lubrication unit must be operated manually

However, an additional disadvantage of the lubrication unit is a potential pollution of the driving gas with lubricant. In case of leakage, the Sulphur hexafluoride in the high voltage vessel might also be affected. To avoid this risk, a lubrication-free turbo generator would be beneficial, which is why a further prototype will be built in which the ball bearings are replaced by gas bearings. Furthermore the new turbo generator will work with pure nitrogen in a closed circuit instead of ambient air in an open circuit. But the price for the lubrication free turbo generator is that special precautions need to be taken. Firstly, the installation position is mandatory and not optional (the inlet side must be on the top) and secondly the gas bearings require a special start procedure to reduce the wear. Before the nitrogen can enter the GET, it must be started smoothly in the "motor mode". That means the generator operates as a motor and causes the gas bearings in a slow rotation movement. If a certain rotation speed is reached, the turbo generator can be used in the usual way. This turbo generator is currently in development and its delivery is expected at the end of the year. It will be later implemented in the HV-solenoid test set-up from BINP SB RAS.

Another open question is the driving gas itself. Because the turbo generator will work in a Sulphur hexafluoride environment, Sulphur hexafluoride would be the ideal driving gas. But the generation of compressed Sulphur hexafluoride to drive a 5 kW turbo generator is another challenge. So far we have not been able to identify a commercial compressor system for Sulphur hexafluoride which would offer attractive operating conditions. A solution could be an Organic Rankine Cycle (ORC) with Sulphur hexafluoride, which is investigated by LTTT in a feasibility study [5]. However, a first analysis has shown, that pressures of the order of 40 bar would be needed. This would require research and development effort for the turbines and the gas distribution system. We therefore favour using dry nitrogen as a medium and to use a conventional compressor stage. A small portion of nitrogen in the Sulphur hexafluoride environment is unproblematic, therefore leakage of the nitrogen into the Sulphur hexafluoride environment can be tolerated up to certain extent.

REFERENCES

[1] J. Bosser, Electron Cooling in CERN Acc. School, CERN 95-06, p, 673 (1995).

[2] PANDA Collaboration, Physics Performance Report for PANDA, Strong Interaction Studies with Antiprotons.

[3] A. Lehrach et al., "Beam Performance and Luminosity Limitations in the High Energy Storage Ring (HESR)" , STORI'08, Lanzhou, China.

[4] A. Lehrach et al., "The polarized electron-nucleon collider project ENC at GSI/FAIR", 19th International Spin Physics Symposium (SPIN2010).

[5] A. Hofmann et al., "Turbo Generators for Powering the HV-Solenoids at the HESR Electron Cooler", IPAC 2014, Dresden, Germany.

[6] www.deprag.com

[7] Manual GET

ISBN 978-3-95450-174-8