Long Pulse, High Power Operation of the ELISE Test Facility

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Abstract. The ion source of the ELISE test facility (0.9×1.0 m^2 with an extraction area of 0.1 m^2) has half the size of the ion source foreseen for the ITER NBI beam lines. Aim of ELISE is to demonstrate that such large RF driven negative ion sources can achieve the following parameters at a filling pressure of 0.3 Pa and for pulse lengths of up to one hour: extracted current densities of 28.5 mA/cm^2 in deuterium and 33.0 mA/cm^2 in hydrogen, a ratio of co-extracted electrons to extracted ions below one and deviations in the uniformity of the extracted beam of less than 10 %.

From the results obtained at ELISE so far it can be deduced that for demonstrating the ITER parameters, an RF power of 80 kW/driver will be necessary, i.e. final aim is to demonstrate long pulses (up to one hour) at this power level and a stable source performance. The most crucial factor limiting the source performance during such pulses – in particular in deuterium – is a steady increase in the co-extracted electron current.

This paper reports measures that counteract this steady increase, namely applying a dedicated long pulse caesium conditioning technique and modifying the filter field topology by adding strengthening external permanent magnets. Additionally, RF issues are discussed that prevented increasing the RF power towards the target value.

Although it was not possible up to now to perform long pulses at 80 kW/driver, a significant improvement of the source performance and its stability are demonstrated. The latter allowed performing the very first 1 h deuterium pulse in ELISE.

INTRODUCTION

The neutral beam injection (NBI) system at ITER will be used for heating and current drive [1,2]. An essential part of the NBI beam line is the negative hydrogen ion source, capable of delivering an extracted current of 57 A for 3600 s in deuterium operation and 66 A for 1000 s in hydrogen (corresponding to current densities of 28.5 mA/cm^2 and 33.0 mA/cm^2, respectively).

In order to minimize the destruction rate of negative ions in the accelerator (stripping losses), the source has to be operated at a filling pressure p_{fill}=0.3 Pa. Additionally, to limit the power loads in the extraction system, the amount of co-extracted electrons has to be equal or smaller compared to the extracted negative ions. In order to ensure good beam optics, hence good beam transmission, deviations in the uniformity of the extracted beam of <10 % are required. Up to now, these parameters have not been achieved simultaneously.

ELISE (Extraction from a Large Ion Source Experiment) [3,4] is part of a R&D roadmap defined by the European domestic agency F4E for the construction of the neutral beam heating systems [5,6]: the half-ITER-size ion source of the ELISE test facility (0.9×1.0 m^2 with an extraction area of 0.1 m^2) is an intermediate step between the RF driven prototype source (0.3×0.6 m^2 with an extraction area of typically $6\cdot10^{-3}$ m^2) [7] and the ion source for the ITER NBI system (1.0×2.0 m^2 with an extraction area of 0.2 m^2) [8]. The latter is in principle identical with the ion source used at the SPIDER and MITICA test facilities under construction at the neutral Beam Test Facility PRIMA in Padova [9,10] and the ion source for the ITER diagnostic beam [2].

Previous experimental results obtained at ELISE – for low RF power as well as short pulse, high RF power operation – were rather encouraging with respect to the ITER requirements. In hydrogen operation, current densities of 25 mA/cm^2 at the required source filling pressure of 0.3 Pa with an electron-ion-ratio well below one could be achieved during short pulses (20 s plasma, 9.5 s beam extraction). In deuterium operation, however, a pronounced temporal instability of the co-extracted electron current limited the pulse length to about 3 seconds. For both isotopes an extrapolation of required RF power with the extracted current density indicated that about 80 kW per driver might be sufficient for achieving the required ITER current densities [11].

The experimental campaign reported in this paper is dedicated to long pulse operation (up to one hour in deuterium, 1000 s in hydrogen) with high RF power (target value: 80 kW/driver). Investigated is how to stabilize the increase in the co-extracted electron current by a dedicated long pulse caesium conditioning technique and by modifying the topology of the magnetic filter. Due to RF issues the maximum RF power available during these long pulse investigations was restricted to 37.5 kW/driver.

THE ELISE TEST FACILITY

A schematic view of the ion source of ELISE can be seen in Figure 1. The plasma is generated by inductive RF coupling into four cylindrical drivers (P_{RF}<90 kW/driver) and then expands towards the extraction system. ELISE is operated in pulsed mode: plasma pulses are possible up to one hour, with short extraction phases, so-called beam blips (length: ≤10 s) at an interval of ≈150 s.

Negative hydrogen (or deuterium) ions are produced predominately by the surface effect, the most relevant converter surface being the surface of the plasma grid (PG, the first grid of the multi-grid, multi-aperture extraction system). The work function of the PG is effectively reduced by depositing a thin (several monolayers) layer of caesium which decreases the surface work function and thus increases the conversion yield for impinging hydrogen atoms into negative hydrogen ions: depending on the energy of the atoms it can reach up to 26 % [12].

The surface work function at the PG can deteriorate by reactions with impurities (from the background gas) embedded into, or deposited on, the caesium layer. This deterioration is the main factor causing non-reproducibility between pulses and temporal instabilities during pulses. To fulfil the ITER requirements for the NBI source, the caesium flow onto the PG should be sufficient to counteract these deteriorating effects and ensure a low work function at the PG that is homogeneous over the area of the PG and stable over pulses up to one hour.

A horizontal magnetic field – the so-called filter field – with a strength of a few mT (sufficient for magnetizing electrons but not the ions) plays a crucial role for the suppression of the co-extracted electron current and also for the transport of negative hydrogen ions to the extraction apertures [13]. The magnetic filter is generated by a current, I_{PG}, flowing through the PG in vertical direction [14]. By varying I_{PG}, the strength of the filter field can be adjusted. The ELISE system is designed for currents up to 8 kA, the currently installed power supply can deliver up to 5.3 kA at maximum and usually the applied current is below 4 kA (equivalent to a field strength about 3.8 mT at the horizontal and vertical center of the PG surface).

The number of co-extracted electrons is reduced by a factor of up to ten (depending on the source parameters) by the magnetic filter. Reason is a low probability for cross-field transport of magnetized electrons, resulting in a reduced electron density in the plasma volume close to the extraction system. An additional reduction of the co-extracted electrons is obtained by a positive bias potential applied to the PG with respect to the source body that is electrically connected to the so-called bias plate [7], see Figure 1.

The co-extracted electrons are magnetically deflected onto the surface of the extraction grid, i.e. the extraction grid is acting as an electron dump. If the power deposited onto this grid is too high, beam extraction is stopped by a safety interlock. The design limit of power deposited onto the extraction grid is 200 kW per segment [3], the safety interlock takes effect at 125 kW/segment. If the co-extracted electron current strongly increases during a pulse it can limit the length of the pulse. Thus, a high co-extracted electron current can prevent increasing the extraction voltage or the RF power which would be required to further increase the extracted negative ion current. Typically, in deuterium plasmas the amount of co-extracted electrons is higher [15] and the

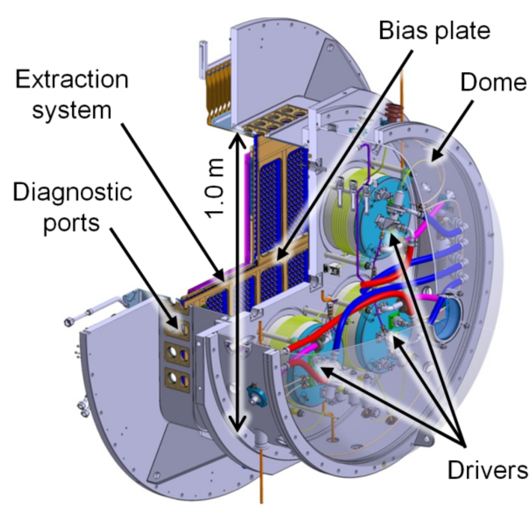


FIGURE 1. Schematic view of the ELISE ion source.

temporal instability of the co-extracted electrons is more pronounced than in hydrogen [15].

CAESIUM CONDITIONING FOR LONG PULSES

For reaching a low and stable surface work function at the surface of the PG, a series of dedicated caesium conditioning pulses is necessary. These conditioning pulses are repeated until a good and stable source performance has been reached. During conditioning caesium is redistributed to create suitable reservoirs inside the source, resulting in an improved subsequent source performance, i.e. an increased stability and/or higher extracted ion currents and/or lower co-extracted electron currents. Caesium conditioning usually is done at low RF power level and with short pulses (length: 20 s, one beam blip) at a filling pressure higher than the 0.3 Pa required for ITER (it has been demonstrated by previous investigations [16] that increasing the filling pressure is beneficial for the caesium conditioning procedure).

While the procedures related to caesium conditioning for short plasma pulses (plasma pulse length: several seconds) were investigated in detail at the small prototype source [17,18], less experiments regarding long pulses (plasma pulse length: up to several hundreds of seconds) have been done at the prototype source [18,19] and at ELISE [16].

For low RF power (P_{RF}=20 kW/driver) stable long pulses up to a plasma pulse length of 450 s (four beam blips) have been demonstrated at ELISE in hydrogen with an electron-ion-ratio well below one but only a small extracted negative ion current density j_{ex} of below 10 mA/cm^2 [16]. It is known that most measures increasing the extracted negative ion current (namely increasing the RF power [19], increasing the extraction voltage and decreasing the filter field strength) can result in a higher temporal instability during long pulses, mainly a more pronounced increase with time of the co-extracted electrons. This effect is correlated with the influence of the source and plasma parameters on the caesium reservoirs and the caesium flow towards the PG and consequently the PG work function during the plasma pulses.

Results recently obtained at ELISE demonstrate [20] that the following conditioning technique can significantly improve the long pulse stability of the co-extracted electrons: first, establish during a series of short conditioning pulses an apparently stable status of the caesium conditioning. Second, perform one or more long pulses with low filling pressure. And third, repeat the series of short conditioning pulses. Although the source is de-conditioned during the long pulses, the modified caesium distribution caused by the longer interaction of the caesium reservoirs with a plasma at a reduced filling pressure has an advantageous long-term effect.

By reproducing the described procedure several times, it was possible to significantly improve the stability of the co-extracted electrons. This can be seen in figure 2a, showing in full lines time traces of the extracted negative ion current density and the co-extracted electron current density obtained during four long pulses with identical source parameters (plasma pulse length 170 s, two beam blips with 9.5 s length each, I_{PG}=2.2 kA, p_{fill}=0.35 Pa, P_{RF}=30 kW/driver, extraction voltage U_{ex}=5 kV and bias current I_{bias}=55 A). In between these four pulses short conditioning pulses have been performed at an elevated filling pressure until a stable source performance has been reached. The interconnecting dashed lines act as a guide for the eye and indicate the change of the signals between the two beam blips. The beam blips are indicated by grey bars.

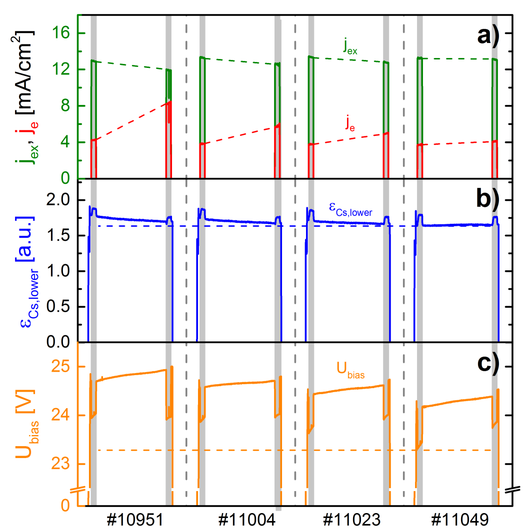


FIGURE 2. Temporal dependence of different signals taken during source conditioning for long pulses (t_{plasma}=170 s) with two beam blips at P_{RF}=30 kW/driver, p_{fill}=0.35 Pa and I_{PG}=2.2 kA. The beam blips are indicated by the grey bars. a) Current density of the extracted ions and co-extracted electrons. b) Caesium emissivity measured along a horizontal line of sight in the lower part of ELISE. c) Bias potential.

The stability of the extracted ion current density and the co-extracted electrons improve from pulse to pulse. The relative increase of the co-extracted electrons between the first and the second beam blip reacts strongly on the progress of the caesium conditioning: while for the first plasma pulse an increase by a factor of about two is observed, for the last long pulse of the series almost stable conditions are reached.

The improvement of the pulse stability is accompanied by only small changes in the plasma parameters, as demonstrated by figure 2b and 2c: figure 2b shows in full lines the time traces of the Cs_{852} emission measured during the four performed long pulses by a caesium diode (horizontal line of sight in the lower part of the plasma). The caesium emission is correlated to plasma parameters like the caesium density, the electron density and the electron temperature. For quantitative statements absolutely calibrated measurements as well as the application of an appropriate population model are necessary [21]. During each of the four pulses a continuous slope of the Cs emission is seen, with two phases of slightly increased emission during the two beam blips, correlated with the increased caesium release from the back plate caused by the back streaming ions, i.e. positive ions created in the acceleration system by collisions of beam particles with the background gas and accelerated back into the source by the acceleration and extraction potentials [22]. A short spike of the cesium signal can be seen at the beginning of each of the four pulses. This spike is correlated to the gas puff (p_{fill}≈1.2 Pa) needed for plasma ignition.

With improving pulse stability both a reduction of the absolute caesium signal and a flattening of the temporal profile is seen (the horizontal dashed line in Figure 2b indicates the minimum caesium emission measured during the four pulses). Although this effect is small, it indicates that a more stable source performance is correlated with more stable time traces of the Cs emission.

Shown in Figure 2c is the bias potential U_{bias} measured during the four long pulses. By keeping the bias current constant during pulses – instead of the bias potential – the net charged particle flux onto the PG is kept constant. It was demonstrated at the prototype source that this operation scenario is beneficial for obtaining stable operation [7,23]. The full line represents the measured bias potential and the horizontal dashed line the lowest value measured during the four pulses. The general temporal behavior of U_{bias} within single pulses (it increases slightly during the plasma pulse but is significantly decreased by the influence of the extraction voltage during the two beam blips) is not altered during the conditioning process. The relative decrease of the bias potential during the beam blips shows no correlation with the conditioning status. However, the absolute value measured during the RF phase is noticeably reduced (by around 7 %) between the first and the last pulse of the performed series. This indicates that the observed stabilization of the caesium emission (Figure 2b) and the improved long pulse stability are correlated with a modification of the potential distribution in the plasma volume (during the RF phase of the pulses).

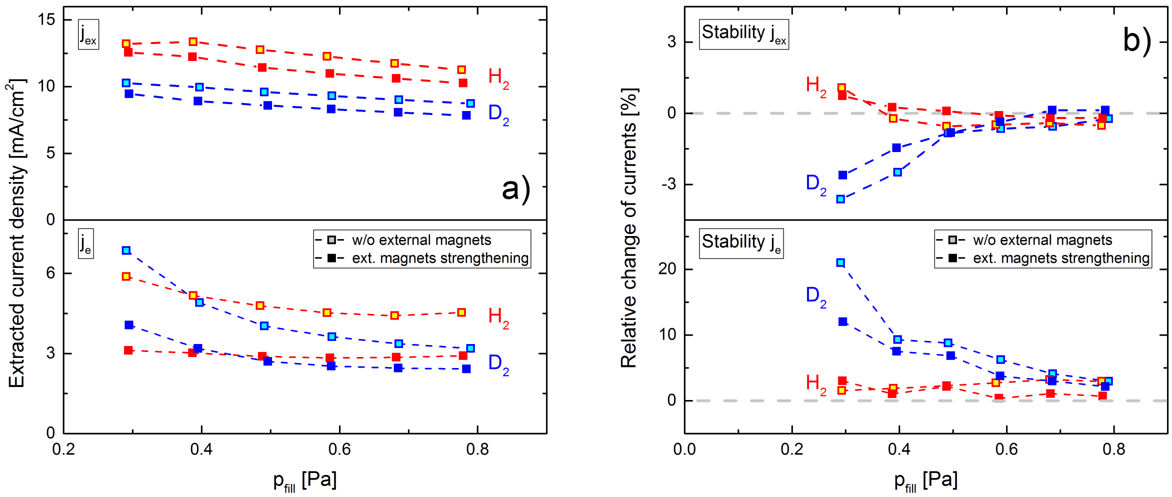
The observed slight modifications of the caesium emission and the bias potential during the conditioning process is correlated with the complex physics of the extended boundary layer: the plasma parameters as well as the potential distribution in the plasma are a result of the interplay of charged particle fluxes from the bulk plasma (electrons, positive ions and volume produced negative ions) and the PG surface (surface produced negative ions) with the magnetic filter and the PG bias potential [24]. For a comprehensive description of the extended boundary layer physics in caesiated negative hydrogen ion sources the application of full 3D models is necessary. Up to now only first steps towards such a full description have been done [25,26,27]

INFLUENCE OF THE MAGNETIC FIELD TOPOLOGY

The standard configuration of the magnetic filter field of ELISE is generated solely by the current I_{PG} flowing through the PG. Although this filter field concept has proven to enable a good source performance [16], it is by far not optimized yet. Thus, investigations have been performed on the question if the source performance and the pulse stability can be further improved by modifying the filter field topology.

Used was the simplest way for modifying the field topology, namely the addition of CoSm permanent magnets to the two vertical side walls of the ion source [28,29,30]. These magnets (horizontal/axial/vertical cross section: 3.9 cm×0.9 cm×110 cm) have been attached to the side walls of the ELISE vessel in the smallest possible axial distance to the PG, 7.5 cm, defined by the diagnostic ports in the side walls close to the PG [3]. The polarization direction of the external magnets is parallel to the main component of the I_{PG} field. Shown here are results of two different field configurations: without the external magnets (only the I_{PG} field, this is called the standard field configuration) and with the additional magnets strengthening the I_{PG} field. In the latter case the I_{PG} field is increased by approximately 1 mT at the surface of the PG in the projection of the horizontal and vertical center of one of the drivers.

It is found that the strengthening configuration of the external magnets has a distinct beneficial impact on the source performance [28,29,30]. Shown in figure 3 is for hydrogen and deuterium and short pulses (20 s plasma, 9.5 s beam extraction) how the absolute values of the extracted current densities and their relative change during the beam



(a) (b)

FIGURE 3. Extracted negative ion current density j_{ex} and co-extracted electron current density j_e for short pulse low power operation (one beam blip with 9.5 s, P_{RF}=20 kW/driver) with and without the strengthening external magnets vs. the filling pressure. a) Absolute values of the current densities. b) Relative change during the course of the beam pulse.

blip react on the strengthening magnets for different values of p_{fill}. Identical source parameters – if possible – have been used for the two isotopes: P_{RF}=20 kW/driver (i.e. low power operation) and I_{Bias}=55 A. Due to the generally much higher amount of co-extracted electrons in deuterium different values for U_{ex} (hydrogen: 4 kV, deuterium: 3 kV) and I_{PG} (hydrogen: 2.5 kA, deuterium: 4 kA) have been used.

For both isotopes and for both magnetic field configurations the absolute value of the extracted negative ion current density j_{ex} (upper part of figure 3a) increases slightly with decreasing filling pressure. With the external magnets (full symbols) j_{ex} decreases by approximately 10 % compared to the measurement in the standard field configuration (open symbols). This factor is roughly identical for both isotopes and it depends not on the filling pressure. Only at 0.3 Pa the decrease in j_{ex} is for both isotopes slightly below 10 %.

With decreasing filling pressure, the absolute value of the co-extracted electron current density j_e (lower part of figure 3a) increases; this effect is more pronounced in deuterium than in hydrogen and it demonstrates one of the main issues in operating NNBI ion sources, namely operation in deuterium at low filling pressure. While for p_{fill}=0.8 Pa j_e for deuterium is smaller than for hydrogen (caused by the reduced values of U_{ex} and I_{PG} compared to hydrogen operation), with decreasing filling pressure j_e in D_2 increases significantly stronger than in H_2. The strengthening field configuration causes a pronounced decrease in j_e that gets more effective with decreasing filling pressure.

The slight reduction of j_{ex} caused by the modified filter topology can be compensated by slightly increasing the RF power while maintaining a significantly reduced amount of co-extracted electrons.

For low pressure operation in deuterium a much more pronounced pulse instability is observed, as illustrated in figure 3b, showing the relative change (in percent) of j_{ex} (upper part of figure 3b) and j_e (lower part of figure 3b) from the start of the beam blip to its end.

In hydrogen operation during short pulses, both the extracted negative ion current density and the co-extracted electron density show a stable behavior without and with the strengthening magnets, independently on the filling pressure. In contrast, in deuterium, the temporal behavior of both ion and co-extracted electron current depend on the filling pressure: while for $p_{fill}\geq$0.7 Pa the results are comparable to hydrogen, for decreasing the pressure towards 0.3 Pa a much stronger pronounced increase in j_e is observed during the beam blips, accompanied by a slight decrease of j_{ex}.

The decrease of j_{ex} with increasing j_e over the pulse length can be explained by an increasing electron density in the plasma volume close to the extraction apertures, resulting in an increased negative space charge generated by these electrons and additionally an increased probability for destruction of negative ions by electron collision. Using the additional external magnets, the temporal increase in the co-extracted electrons in deuterium is reduced by more than 40 % and consequently also the decrease of the extracted negative ion current density is weakened.

A series of dedicated conditioning pulses without and with the strengthening magnets was used to identify two different physical effects responsible for the beneficial impact of the external magnets on the source performance:

first, the modified field topology directly influences the plasma structure. And second, the modified plasma structure significantly affects the trajectories of caesium ions. Over the course of a series of short conditioning pulses these modified trajectories result in a new (and beneficial) status of the caesium conditioning. Both the direct effect of the additional magnets on the plasma structure and their impact on the caesium conditioning can affect, even in opposite directions, the amount and the (vertical) profile of the co-extracted electrons.

Figure 4 shows the extracted negative ion current density and the co-extracted electron current density for the best pulses performed up to now (using the long pulse conditioning technique described in the previous section and the strengthening external magnets) at 0.3 Pa in hydrogen (figure 4a) and deuterium (figure 4b). Both pulses have been performed at reduced source parameters. In hydrogen (P_{RF}=37.5 kW/driver, p_{fill}=0.3 Pa, I_{Bias}=20 A, U_{ex}= 8 kV, I_{PG}=2.8 kA) a reduced value of the RF power was used due to technical reasons (see below) while in deuterium (P_{RF}=20 kW/driver, p_{fill}=0.3 Pa, I_{Bias}=40 A, U_{ex}= 4.5 kV, I_{PG}=4.0 kA) the parameters had to be reduced in order to keep the electron-ion-ratio below one during the full length of the pulse.

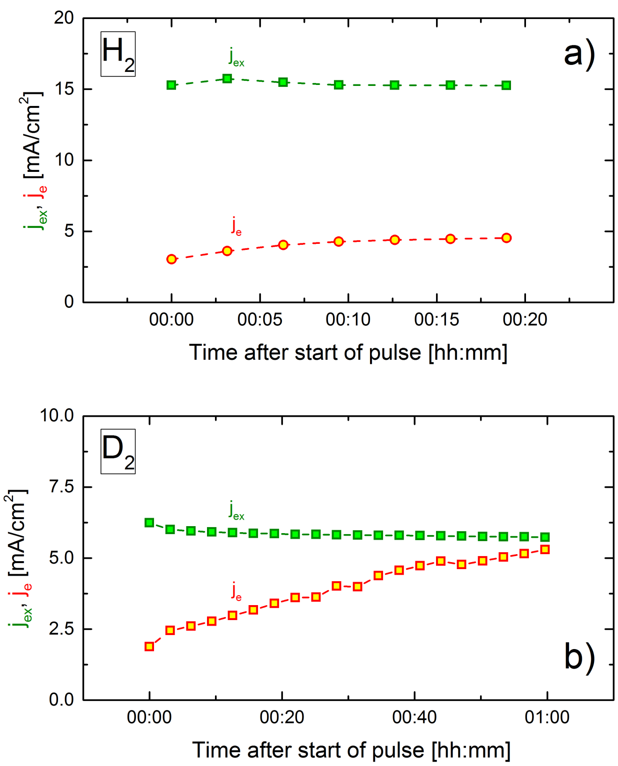


FIGURE 4. Extracted negative ion current density and co-extracted electron-current density for the best pulses with ITER relevant pulse length performed in ELISE up to now at p_{fill}=0.3 Pa and with the strengthening external magnets. a) Hydrogen. b) Deuterium.

The obtained performance in hydrogen (j_{ex} above 15 mA/cm^2, i.e. approximately 46 % of the ITER requirement, and an electron-ion-ratio below 0.3) and in particular the temporal stability of the extracted currents (only a slight change of the extracted currents over the pulse length) is significantly better compared to the best long pulses without applying the long pulse conditioning technique and without the external magnets.

The pulse shown in figure 4b is the first one hour deuterium pulse performed at ELISE: without the external magnets such pulses have not been possible. The stability of the extracted currents, however, is not satisfying: while j_{ex} decreases only slightly (above 5.7 mA/cm^2) during the pulse, a steady increase in the electron-ion-ratio is observed (from 0.30 for the first beam blip to 0.92 for the last beam blip).

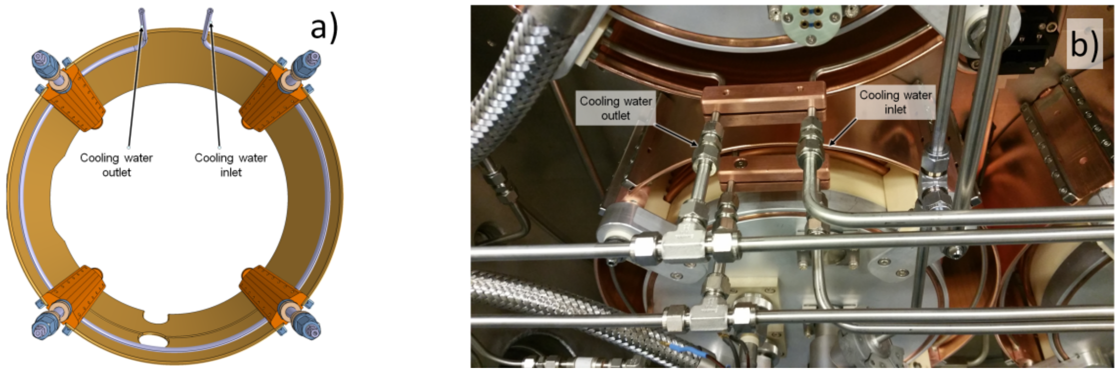
RF ISSUES

Beside the amount and stability of co-extracted electrons technical issues, e.g. RF breakdowns in the dome outside of the drivers and temperature increase of some RF components prevented increasing the RF power towards the target value of 80 kW/driver.

In order to reduce the probability of RF breakdowns and for ITER like RF operation the four RF drivers of ELISE are operated in vacuum; this vacuum is enclosed by the so-called dome (see figure 1). The typical pressure in the dome volume is around 10^{-6} mbar, maintained by a dedicated turbomolecular pump and a forepump. The dome vacuum is being separated from the source and beamline vacuum.

During all experimental campaigns of ELISE RF breakdowns occurred randomly in the dome volume. Initially, these breakdowns could be conditioned away, i.e. after one dome breakdown the experimental program was continued and the probability for additional dome breakdowns at identical source parameters was decreased. Most dome breakdowns occurred after increasing the RF power above the maximum value used previously.

With increasing operational time of ELISE the number of RF breakdowns increased and the average RF energy at which they took place decreased (down to P_{RF}=20 kW/driver, the lowest RF power that can be supplied by the generators, i.e. it was not possible any longer to operate ELISE in a reasonable way). This effect is attributed to



(a) (b)

FIGURE 5. Improved water cooling system of the EMS at ELISE, as seen from upstream. a) Schematic view. The driver itself is not shown. b) Detail view of the mounted EMS and the water supply tubes.

particles – mainly dust – produced by previous dome breakdowns and accumulated in the RF feedthroughs. After thoroughly cleaning the feedthroughs and modifying their design in order to optimize the geometry of the triple points (locations where a conductor is in contact with two materials of different dielectric constant) a significantly reduced probability for dome breakdowns is observed. Investigations on this topic, however, are ongoing. These investigations comprise changing the material (from alumina to quartz) and the design of the drivers [31,32].

In order to avoid asymmetries of the RF electromagnetic field in the drivers that could result in damages of the Faraday screens [4], each driver is surrounded by a copper electromagnetic screen (EMS). The initial version of these EMS consisted of two half-shells each and was water cooled by a cooling pipe that was connected to each of the EMS at both joints between the two half-shells.

During plasma pulses with more than several hundreds of seconds a steady increase in the temperature was observed by two thermocouples connected directly to one of the EMS and to one of the driver rods, reaching a final temperature of more than 300 °C (for P_{RF}=30 kW/driver and operation of both generators this temperature is reached after around 1600 s). After the end of some pulses the measured temperature continued increasing, indicating that parts of the EMS have been heated up to even higher temperatures. By evaluating the temperature of the cooling water the fraction of the total RF power deposited in the EMS was determined to be around 1.4 %, i.e. for a RF power of 30 kW/driver the EMS were heated by about 0.4 kW.

The observed increase in the temperature of the EMS contributed to a significant increase in the dome pressure (by more than one order of magnitude, up to 10^{-5} mbar). Although both the increasing EMS temperature and dome pressure presented no immediate risk for the operation of ELISE, due to safety reasons the pulse length at high RF power was limited to max 300 °C EMS temperature. As a consequence the maximum RF power available during long pulses and/or the pulse length was restricted.

In order to overcome this restriction, an improved version of the water cooling system for the EMS was introduced (Figure 5a). All four driver rods are actively cooled by means of deep drilled cooling channels (design value for the water flow: 15.6 l/min; measured after mounting the cooling system was a slightly lower value) and the EMS is attached in 4 quadrants with good thermal contact to those rods. Heat conduction is further increased by increasing the EMS wall thickness from 1.5 mm to 4 mm. [32]. Figure 5b shows a detail view of the dome volume in ELISE after the new EMS have been mounted.

Figure 6 shows the temperature measured at the EMS around driver 2 (the upper right driver) during long pulses with P_{RF}=37.5 kW/driver, the initial and the improved cooling system. For the first 15 s the temperature increase measured for the two different cooling systems is roughly comparable. The final temperature reached with the initial cooling system cannot be determined since 100 s after the end of the plasma pulse the measurement of the temperature is stopped. At this point in time a temperature increase of 180 °C is reached. Using the improved cooling system the temperature of the EMS increases by about 5 °C only and then stabilizes. After switching off the generators (pulse length=1160 s), the temperature of the EMS immediately begins to decrease.

Besides the temperature increase of the EMS a pronounced but yet not critical heating of other components of the RF circuit was observed, including the RF transformer and the band conductors connecting the C1 capacitors with the matching boxes (containing the C2 capacitors and the RF connections to the experiment itself). This temperature increase could result in too high temperatures when increasing P_{RF} and the plasma pulse length towards

80 kW/driver and one hour, respectively. Thus, work was performed or started regarding improving the cooling of these components.

The promising results obtained using the improved cooling system of the EMS demonstrate that – if the remaining technical issues are solved – the door is open for performing 1 h pulses in ELISE with an RF power of significantly more than 40 kW per driver.

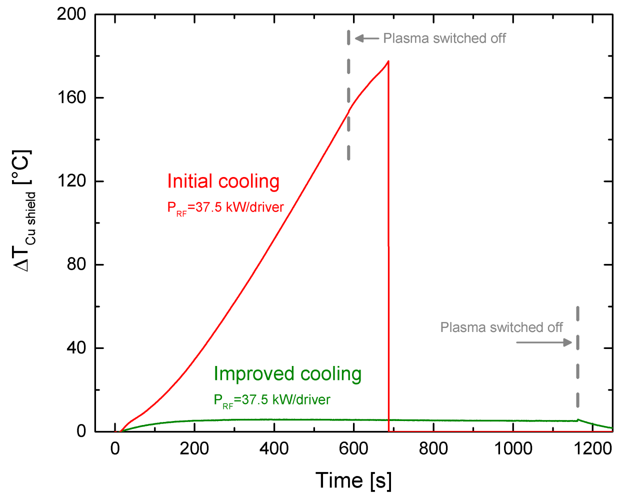


FIGURE 6. Temperature of one of the EMS during long plasma pulses with the initial and with the improved water cooling system.

CONCLUSIONS

Aim of the ongoing experiments at ELISE is to perform long pulses with high RF power. Different physical and technical issues have been tackled up to now in order to enable such pulses and to obtain a stable performance.

It was demonstrated that it is possible to further improve an apparently stable caesium conditioning by deliberately slightly de-conditioning the source (e.g. by performing one or more long pulse with low filling pressure) and then continuing the conditioning process. The de-conditioning pulse can have an advantageous long-term effect on the conditioning status, resulting in a significant improvement of the long pulse stability – in particular of the co-extracted electrons. The results of source diagnostics demonstrate that the performed long pulse conditioning is correlated with only small variations of parameters like the electrostatic potential, the negative ion density and with the content and temporal behavior of cesium in the extended boundary layer.

An additional improvement of the source performance and the long pulse stability is obtained by modifying the topology of the magnetic filter. This was done by adding external permanent magnets that strengthen the field generated by I_{PG}. One of the main results of this modification was that the very first one hour deuterium pulse in ELISE could be performed at ITER relevant pressure. Although the electron-ion-ratio is increasing during the whole length of this pulse, it stays below one.

Additionally several technical issues are under consideration: An improved cooling system for the EMS in the dome drastically reduces the temperature increase of components in the dome, hence the increase in the dome pressure during long pulses with high RF power. In order to avoid RF breakdowns the RF feedthroughs have been modified and different driver materials as well as coil arrangement geometries are in preparation.

Remaining challenges are the RF breakdowns occurring in the dome and the still very strong increase of the electron-ion-ratio during long pulses in deuterium.

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