A test bed for AC operation of Ti sublimation pumps in the NBI system for W7-X

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Motivation

The new Neutral Beam Injection (NBI) system for Wendelstein 7-X (W7-X) [1] is being built as a replica to the one installed on ASDEX Upgrade (AUG) with 2 injectors delivering 10 MW heating power each. Per injector, 4 large titanium getter pumps (1.2 m x 4 m) [2], are used with a total pumping speed of 2.8 x 10^3 m^3/s for Hydrogen. Ti atoms are sublimated from 4 m long hanging Ti composite wires (Ti wires) which are electrically heated using a current of around 140 A. The Ti layers are deposited onto large water cooled surfaces, trapping H_2 and D_2. On AUG the wires are heated by DC current between beam pulses. W7-X is however a superconducting machine that creates a permanent magnetic field of over 3 T inside the vacuum vessel. The outer magnetic stray field at the position of the NBI Ti getter pumps can reach values around 50 mT. The resulting Lorentz force would deflect the wires too much and prevent regular pump operation. Therefore an approach using alternate current (AC) instead of DC for the Ti wire heating has been experimented in a dedicated test facility.

Test Stand description

The vacuum vessel is the standard NBI vessel used on AUG and W7-X which has been modified with additional windows for direct observation of the Ti wires during operation. The Ti getter pump is a spare pump from AUG where only 1 of the 9 chambers is used for this experiment *(fig. 1)*. The neighbouring chambers are used to mount a water cooled copper coil with 5 windings to simulate the W7-X magnetic stray field. A DC power supply for cw operation was selected to power the coils creating at 2.8 kA (15 V) the maximum required magnetic field of 38 mT close to the wires *(fig. 2)*. The chamber is equipped with 3 pairs of wires which are hanging on feedthroughs at the top. At the bottom they are flexibly connected and

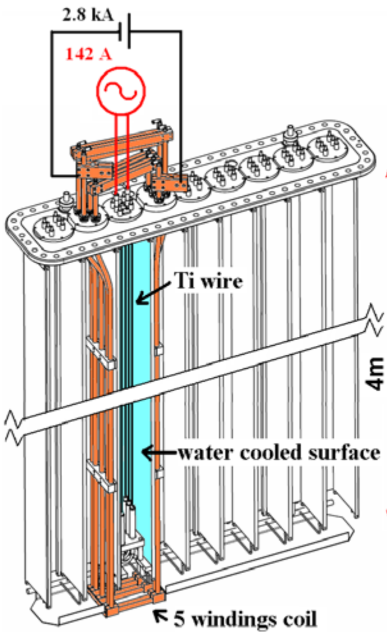

Figure 1: Experiment overview.

guided to allow for thermal expansion. Only one pair is heated at the time, after having depleted most of the Ti, the next pair is used. The composite wire consists of a central Ta wire (ø 2 mm), around which in a first layer, Ti and Mo wires are wound. In a second layer only a Ti wire is wound in the opposite direction. A new AC power supply has been selected with up to 50 kVA (180 A_{rms} / 280 V_{rms} output configuration) to power the wire pairs. It also allows using plenty of different wave forms and frequency configurations from 60 to 1000 Hz. A set of these parameters will be defined for the standard operation on W7-X.

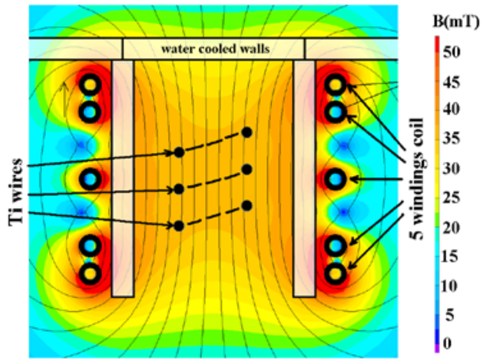

Figure 2: Horizontal cross section of the pump in one chamber with 2.64 kA current in the coil and 36 mT in the Ti wire region.

Phenomena to be investigated

The main concerns associated with the AC heating of the Ti wires in a strong magnetic field and the subsequently strong alternating Lorentz forces are the following:

Wire operation and life time reduction - It was observed already during normal DC operation that the hanging wires do not only have a significant thermal expansion during the heating phase but also suffer from a permanent lengthening, probably caused by creeping. With the oscillating Lorentz forces this phenomena could be worsened. In addition, the Lorentz forces may reduce the life time of the wires due to high-cycle fatigue.

Dynamic behaviour - The pair of wires represents a weakly damped system under an oscillating load. A resonant excitation of higher harmonics could cause very large amplitudes, which depend also on wire characteristics.

Pumping effect - Due to the strong accelerations of the wire up to 10 g by the alternating Lorentz forces, a shake-off effect of small Ti droplets from the wires may happen, preventing the formation of the homogeneous thin Ti layer necessary for a proper pumping.

Diagnostic equipment

CCD cameras - It is used for direct video observation through the vessel windows.

Vibration detection system with microphones - Two microphones are clamped onto the electric feedthroughs of each hanging wire outside of the vessel to measure the transmitted vibration of the wires. The microphones are oriented perpendicular to each other, "listening" to the vibrations in both directions, in the magnetic field direction and perpendicular to it respectively.

Aluminium plate probes - They are attached at the walls so that Ti will also be deposited onto them. The characteristics of the Ti layer (e.g. forming of droplets) can be analyzed afterwards under microscope.

Electrical signals monitoring -Voltage, current and frequency are constantly being monitored and used to control the test stand and to gain extra information of the operated wires.

AC Operation

All components and systems were in a first step successfully commissioned. The approach has been to very cautiously increase from pulse to pulse the constant flat-top current (mostly sinus) in the pair of wires and the magnetic field.

Wire conditioning - The standard procedure for a new pair of wires is an initial conditioning, during which the wires are heated slightly over the Ti melting point. This creates a homogeneous Ti layer along the wire length that better conducts the heat and enhances uniform Ti sublimation. The current should slightly exceed the standard current value. As soon as the electrical resistance drops by typically 10% the wires are properly conditioned [2].

Standard operation - The DC operation used at AUG for the last twenty years [2] has served as basis for the AC operation. The current limit of 142 A DC is taken for the AC RMS current value. The current is ramped up in the first 10-15 s to its nominal value and ramped down in the last 10 s of the 160 s long pulse. During the constant current phase the frequency is changed to avoid possible resonant frequencies *(fig. 3)*. The frequency variation region is between 150 and 800 Hz.

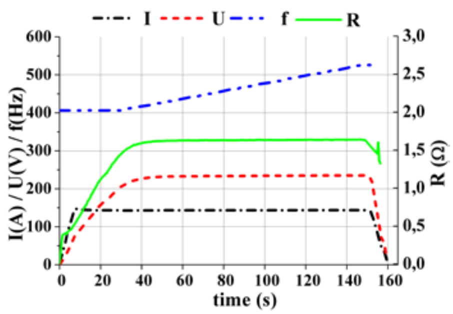

Figure 3: Example of a standard pulse with ramped frequency (400-520 Hz) for sinus 142 A_{rms}

Results and observations

Direct observation of oscillations and displacements - During standard operation, no large amplitudes have been observed. An oscillating behaviour however occurs if the current is ramped too fast or abruptly interrupted.

Permanent lengthening effect - The wire lengthening has already been a critical issue for the AUG Ti getter pumps, since it determines the operation time of a pair of wires until a wire shortening is necessary. The experience within the years is that the lengthening effect is highly

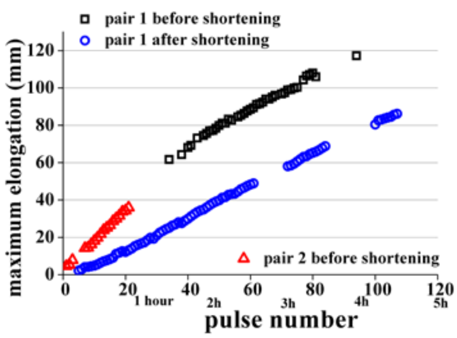

Figure 4: Lengthening of 2 different pairs of wires before and after shortening for AC operation.

dependent on the manufacturing process of the composite wire. In fact, a strong variation is observed with different batches of wires. On figure 4, the maximum relative elongation value (in heated state) is plotted for two pair of wires before and after the shortening. The operation time before the first shortening is comparable for the same wires AC or DC operated, i.e. between 3-4 hours [3]. Nevertheless, a larger statistical basis is required to come to final conclusions about possible differences between DC and AC operation.

Microphone vibration detecting system - This detection system is still under development, although preliminary results *(fig. 5)* indicate a clear correlation between microphone signal and AC frequency, which demonstrates the potential of this system. It is assumed that the signal amplitude is a measurement of the wire vibrational state. This diagnostic could be used to find a set of frequencies with less wire excitation, or at least to avoid the resonances and to assess the influence of wire mass and length on the wire vibrational behaviour.

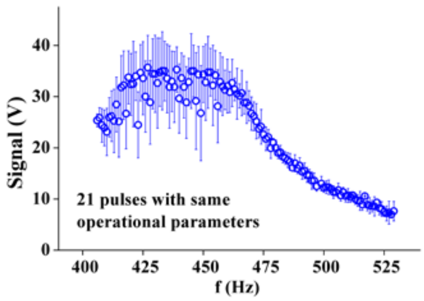

Figure 5: Microphone signal for 21 standard pulses (142 A_{rms}) at max magnetic field and frequency ramp from 400 to 520 Hz.

Tank pressure - A pumping effect is observed whenever the current is set over 125 A_{rms}. From that value on, sublimation starts and consequently the fresh Ti layers start pumping. Visual exam of the probe plates revealed quite homogeneous Ti layers and a microscopic analysis will be performed soon.

Conclusions and overview

The test stand for AC operated Ti getter pumps has been commissioned and tested to its nominal operation parameters. Wire conditioning, lengthening and life time in a strong magnetic field have been shown to be similar to what was observed for DC operation. Based on these positive results, NBI operation on W7-X will start with Ti getter pumps. Further improvements in the test stand diagnostics are being implemented in order to define an optimum sequence of AC parameters for the standard operation. Ti sublimation and pumping effect has been observed, nevertheless a further comparison of AC and DC operation with respect to pumping efficiency is planned.

References

[1] **Rust, N., et al.** *Fus. Eng. Des. 86 (2011), 728-731*

[2] **Feist, J.-H., et al.** *Proc. 17th SOFT, 1992 Rome, Vol.1, pp. 262-266*

[3] **ITED group**, *Internal documentation at IPP*