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Pressure gauge filament for neutral gas density measurement using alternating current as source power☆

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HIGHLIGHTS

- Development of a hot cathode ionisation gauges for neutral gas density measurement using alternatively the alternating current as source for heating power.
- The benefit of such a technique is besides saving of heating power, especially space-saving by applying thinner power supply cables.
- Different filament deigns are presented.
- A numerical analyses is presented, begin with a transient thermal followed by an electromagnetic and finally a structural dynamic analysis.
- The aim of the analysis of the filament heated by AC is to find out the frequency of the heater current for a proposed design (*jxB*).

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ABSTRACT

In plasma fusion research the in-vessel neutral gas density is often measured using hot cathode ionisation gauges which are modified for the application in high magnetic fields and for a measurement range between 10^{-3} Pa and 20 Pa. To obtain sufficient electron emission, the cathode (filament) is heated to high temperatures in the range of 1800 K by direct ohmic heating. To compensate for the induced Lorentz-forces, the filament must be relatively thick to provide sufficient mechanical stability which implicates increases of heating currents up to 20 A.

The heating current could be reduced by using a thinner filament in combination with alternating current with suitably chosen frequency to reduce mechanical stresses. The benefit of such a technique is besides saving of heating power, especially space-saving by applying thinner power supply cables. To estimate the suitability of such a solution a feasibility study by means of numerical methods has been carried out. The main subject of the investigation was the hot-filament for which alternating current has been used as power source. This paper provides first of all the main guidelines and features important in developing a pressure gauge filament heated by alternating current from the mechanical point of view.

1. Introduction

The pressure gauge (PG) type reconsidered in this paper belongs to the hot-cathode or emitting-cathode ionization gauge category [1]. The measurement principle based on kinetic theory of ideal gas law, expressed in the form:

$$P = nkT \quad (1)$$

where P [Pa] is the pressure, n[molecules/m^3] is the molecular density, k [J/K] is the Boltzmann constant and T [K] is the absolute temperature. This is the fundamental equation on vacuum measurement, because it establishes a relationship between pressure and gas density. This measurement method is also called “indirect” since it measures the gas density via the strength of ionisation process and not directly the pressure. The hot-cathode or usually called filament is the key part of the PG equipment. The filament provides an electron emission current which ionises the surrounding gas and produces an ion current. Both currents are collected at electrodes kept at an appropriate electric potential. Naturally, the filament operating temperature is quite high, around 1800 K, and is heated by either DC or AC current. Although, the current source does not influence the measurement procedure, there are some advantages or disadvantages in the application and design. In case of DC driven

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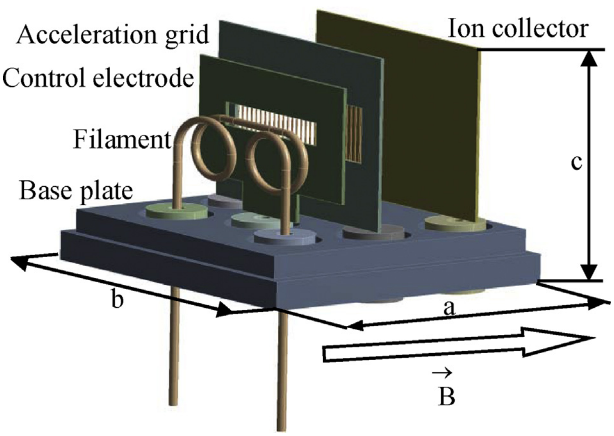

Fig. 1. Pressure gauge main parts assembly.

heating, there is no risk of disturbance for surrounding equipment. The AC driven heating offers potentially lower Lorentz stresses in the filament if operated within a magnetic field, which in turn enables to use a thinner filament and thus lower heating power. On the other hand, a suitable frequency modulated AC source and possibly an electromagnetic shielding are needed.

2. Pressure gauge design

The geometry of the PG filament used in the analysis is based on the ASDEX Upgrade PG which operates with direct current [2]. Compared to other PGs, which work with a similar principle, the PG developed at IPP (Fig. 1) differs mostly in the "linear" electrode arrangement.

The orientation, marked in Fig. 1 by $\vec{B}$ within the magnetic field is important for the proper functionality of the PG [2]. The assembly consists of a filament made of tungsten or tungsten alloy and control electrode, accelerator grid, ion collector made of stainless steel. All parts are ceramics insulated and fixed by brazing in the base plate made of stainless steel. The outer outline of the so called head is a*b*c ≈ 20*20*20 mm. Among all other equipment parts only the filament part will be the main subject of analyses in this paper. Beside of the filament shape called "spirally" (Fig. 1) the shape called "planar" (Fig. 2), has been considered as well. Since the filament wire diameter (θ) for DC driven heating is typically 0.6 mm, for AC driven heating two wire diameters 0.2 mm and 0.4 mm have been considered in the numerical analyses.

3. Numerical simulation and discussion

The aim of the numerical analysis or structural optimisation of the filament heated by AC is to find out temperature. That is the reason why we use the approximately sign for the target temperature. Moreover, the filament operating temperature is not a fix value, it depends on work function and thus is not constant. For the choice of the AC frequency range the parameters of commercial equipment were considered. Fig. 4 shows the FE model with exemplarily "planar" filament and different material mixture. With the aim to avoid possible inaccurate results for filament stresses the frequency of the heater current for a proposed design until the stresses or displacements caused by alternating Lorentz-forces (*jxB*) become acceptable (i.e. are below material limits). The applied procedure of the filament structural optimisation by numerical simulation is shown in Fig. 3. The analyses begin with a transient thermal followed by an electromagnetic and finally a structural dynamic analysis. The above listed procedures have to be repeated in a do loop to improve the design and/or boundary conditions (BC) until the optimisation conditions (stresses or displacements) are satisfied. The designation above the boxes are the single analysis input parameters and the entities below are the analyses outputs.

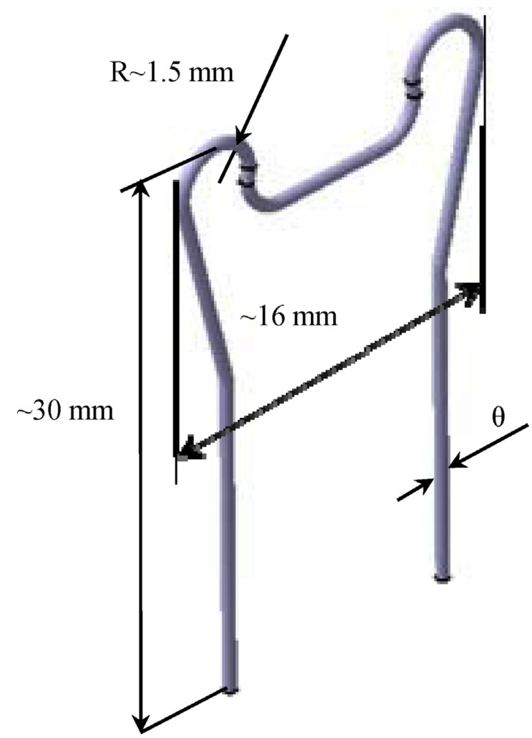

Fig. 2. Filament shape called "planar".

Two finite element (FE) models with different filament shapes have been prepared as follows:

- Filament shape = "spirally" and "planar"
- Filament wire diameter = 0.2 and 0.4 mm
- AC amplitude (I_0) = 2.0, 4.0 and 6.0 A
- AC frequency = 1–50 kHz
- Target temperature = ∼1800 K (±100 K)

In theory the current is defined by the filament diameter for a certain material and the target manufacturing process (brazing) should be taken into account by the numerical simulations.

Pure tungsten material properties [3] have been used in present analysis. The FE model main features like filament material properties, electrical resistivity, thermal conductance and radiosity are defined entirely as temperature dependant. For these analyses the commercial numerical analysis package ANSYS [4] including the MAXWELL extension have been used.

Fig. 5 shows the result plot of the transient thermal analysis of the "spirally" filament. This analysis has been performed for a filament made of tungsten with a wire diameter of 0.2 mm and heated by AC current with an amplitude of 2.0 A. Main boundary conditions are the bulk temperature defined as 300 K and the base plate temperature defined as 600 K. The AC frequency does not play any role for filament heating since the AC frequency range does not induce any skin effect in the present wire cross-section. Additionally, the parametric transient temperature analysis provides the optimal effective filament length at approximately 60 mm. The effective filament length (hot part) is the part above the base plate between both fixations. Accordingly, the maximal temperature does not rise if the effective filament length increases.