QUENCHING OF THE POTENTIAL RELAXATION INSTABILITY IN A SINGLE-ENDED Q-MACHINE PLASMA WITH NEGATIVE C_{60} IONS

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1. Introduction

A number of low frequency instabilities are driven by electron currents. Due to their low mass and therefore high mobility, electrons react about two orders of magnitude faster on potential changes than ions. A strong electron current along the magnetic field of a Q-machine gives rise to large amplitude relaxation oscillations of the space potential and the current. These oscillations are associated with a moving double layer and are usually referred to as the **p**otential **r**elaxation **i**nstability (PRI) [1]. Although this kind of instability was observed in a Q-machine for the first time, PRI-like oscillations can be observed in low density current carrying bounded plasma systems.

Here we present the results of an investigation on the influence of heavy C_{60}^- ions on the PRI. The fullerene C_{60} has a large cross section for electron attachment at thermal energies [2]. The electron temperature in a Q-machine is about 0.2 eV. Thus, by introducing C_{60} vapour into the plasma column a significant part of the plasma electrons can be replaced by C_{60}^- ions [3]. Since an essential feature of the mechanism that drives the PRI is the loss of negative charge carriers by the positive voltage of the CP and the inertia of the positive charge carriers, the instability will be strongly influenced by the C_{60}^- ions. The loss of negative charge carriers due to the positive voltage of the **c**old **p**late (CP) will decrease because of the low mobility of the C_{60}^- ions, although the quasineutrality of the unperturbed C_{60} plasma is still valid and reads: $n_+ = n_- + n_e$, where n_+ is the density of the potassium ions and n_- is the density of the C_{60}^- ions.

2. Experimental Setup

The measurements have been carried out at the single ended Q-machine of the University of Innsbruck. A schematic of the experimental setup is shown in Fig. 1. A potassium plasma is produced by surface ionization of K-atoms on a **h**ot tungsten **p**late (HP). The radial confinement is provided by a magnetic field with a strength of 0.1 - 0.22 T. Usual plasma densities are about 10^9 cm^{-3}. C_{60} powder is evaporated in a source mounted at a distance of 17 cm from the HP. In order to minimize the disturbance of the plasma the source is kept at floating potential. At temperatures of about 450°C C_{60} evaporates and heavy negative ions are formed due to the electron attachment reaction: $C_{60} + e^- \rightarrow C_{60}^-$. The plasma is terminated by the electrically floating CP. For most of the measurements presented here the distance between

the HP and the CP, representing the system length, was 33 cm, but it could be varied. To excite the PRI, the CP was biased with a positive voltage in the range between 3 - 10 V.

Fig. 1: Schematic of the Innsbruck Q-machine.
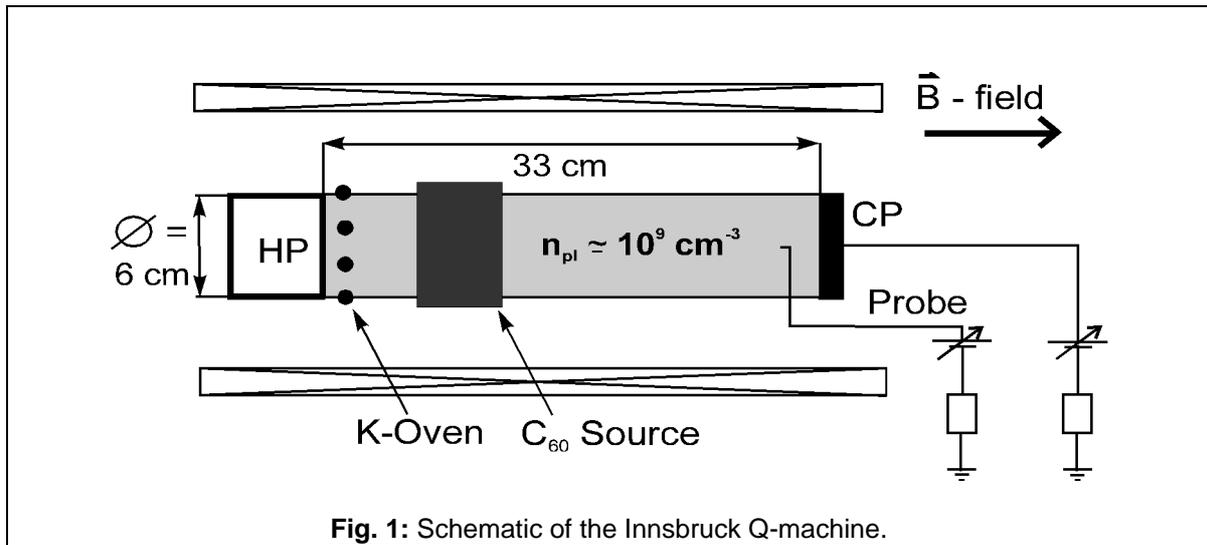
To determine the plasma parameters an indirectly heatable Langmuir probe was used [4] which could be moved axially and radially. Since the mass number of the C_{60}^- ions is very high (720 amu), their contribution to the total negative current is negligible and from the decrease of the electron saturation current we can estimate the negative ion density [3].

3. Results

When the CP was biased with +3 V, the PRI was excited with a frequency of 5.5 kHz. Under these conditions C_{60} molecules are added to the plasma column by heating the C_{60} source. Fig. 2 shows the frequency spectra of the AC component of the cold plate current for 2 different cases in the potassium plasma without C_{60}^- ions, in the plasma where 60% of the electrons are replaced by C_{60}^- ions.

Fig. 2: Frequency spectra in the potassium plasma and in the C_{60} plasma.
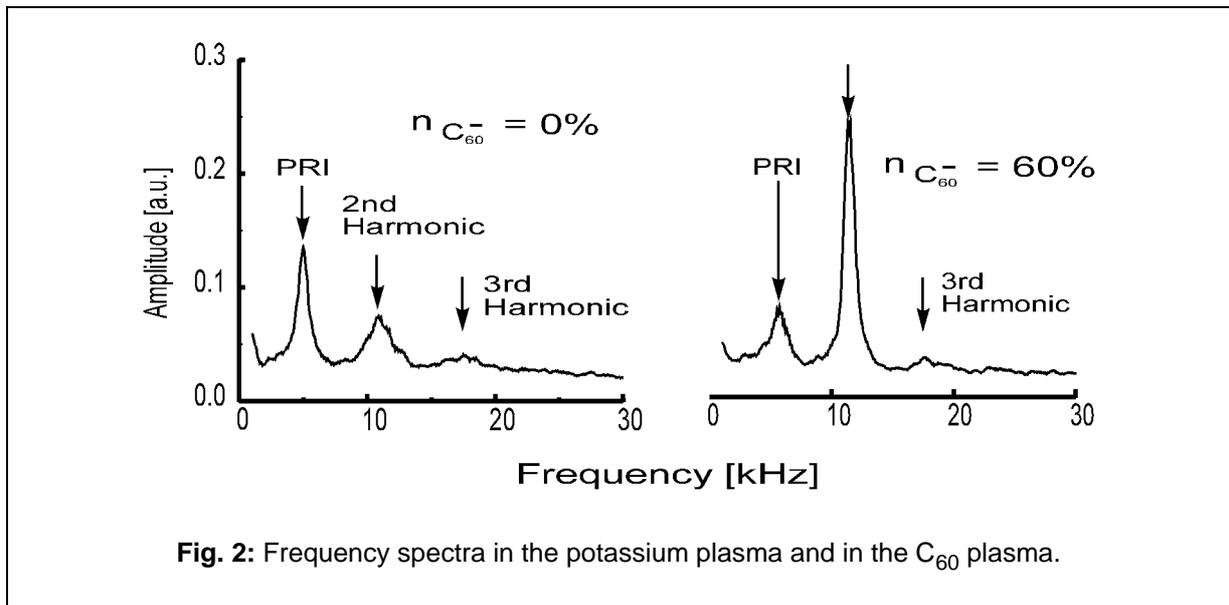
We notice that the PRI and its 2nd and 3rd harmonic are excited. With an increasing density of C_{60}^- ions, which is equivalent to a decreasing electron density, the PRI is quenched and simultaneously an oscillation at a frequency of about 12 kHz rises. This peak will henceforth be called the C_{60} oscillation From now on we will call this additional oscillation C_{60} oscillation. Its amplitude increases with increasing C_{60}^- density and its bandwidth is very small. By introducing C_{60}^- ions the total number of negative charge carriers does not change. However, the effective loss of negative charge carriers by the positive bias of the CP is reduced due to the high mass of the C_{60}^- ions and therefore their lower mobility. Thus the quenching of the PRI oscillation becomes understandable.

It is obvious that the frequency of the growing oscillation is about twice the PRI frequency. Thus, we have checked whether this peak is in truth simply the 2nd harmonic of the PRI that is amplified. It is well known that the PRI frequency is inversely proportional to the system length. Fig. 3 shows the inverse frequency of the various oscillations versus the system length. In the spectra of the CP the 1st harmonic of the PRI, the C_{60} oscillation and the 3rd harmonic of the PRI can be seen.

Fig. 3: Inverse frequency of the various oscillations versus the system length.
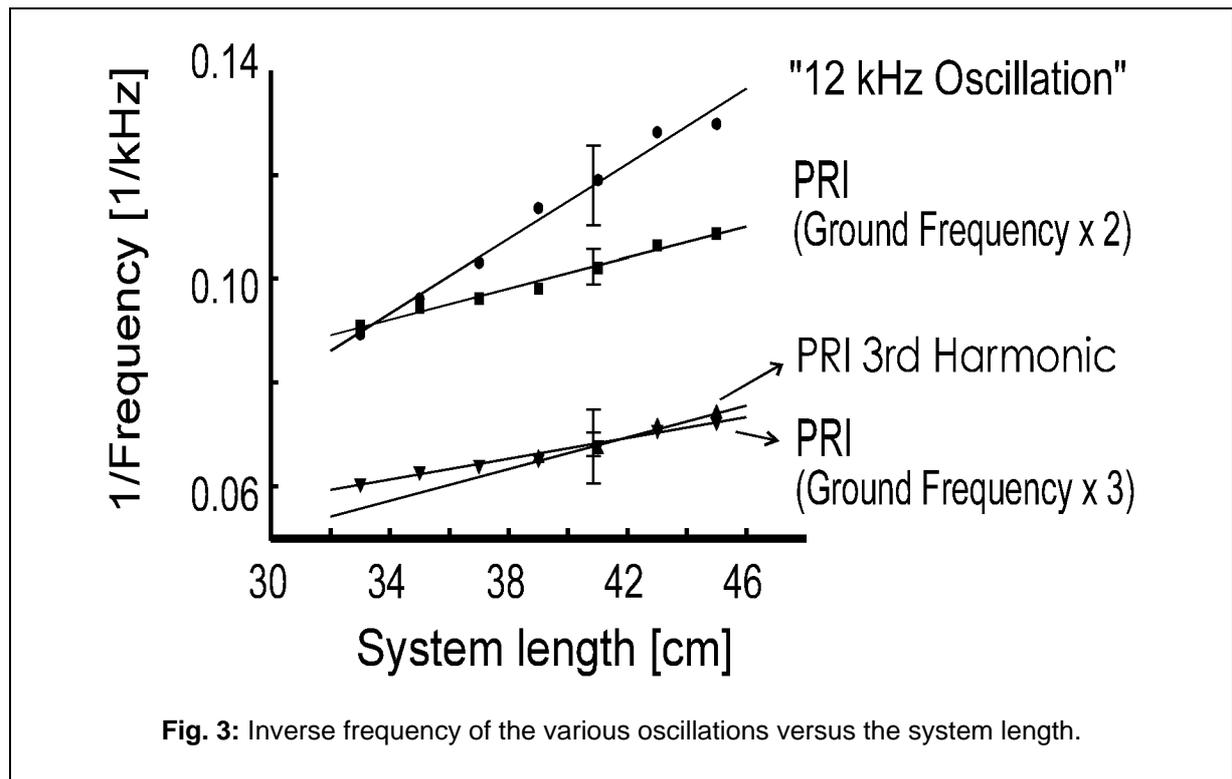
By multiplying the 1st harmonic of the PRI with 2 and with 3 we get the 2nd and the 3rd harmonics of the PRI. Fig. 3 shows a good agreement in the case of the 3rd harmonic, however in the case of the 2nd harmonic for larger system lengths we get a clear difference between the additional oscillation that appears by introducing C_{60}^- ions and the value of the PRI ground frequency times two. Thus, the additional oscillation cannot be the 2nd harmonic of the PRI. On the other hand we see that also this oscillation has a linear dependence on the

inverse system length. This dependence is stronger than that of the PRI since the slope is steeper.

Since the plasma of a Q-machine is magnetized it is interesting to investigate the influence of the magnetic field strength on the quenched PRI and the C_{60} oscillation. The magnetic field strength was varied between 0.1 T and 0.22 T. By increasing the magnetic field the radial confinement of the plasma becomes better, and therefore the plasma density increases. The effective system length is increased due to the decrease of the thickness of the sheath in front of the boundary. As a result the frequency of the PRI decreases [5]. However, this is a very small effect. Fig. 4 shows the frequency of the quenched PRI and the C_{60} oscillation versus the magnetic field strength. There is a slight decrease of the frequency of the quenched PRI oscillation with higher magnetic field strength, however, it is within the error bars. The frequency of the C_{60} oscillation shows a slight decrease of about 1 kHz. Interesting is the behavior of the amplitude of both oscillations as a function of the magnetic field. Since the gyroradius of the C_{60}^{-} ions is about 4 mm for B = 0.22 T and 8 mm for B = 0.1 T one should expect a strong radial loss for weak magnetic fields and therefore a quenching of the C_{60} oscillation. This is true for large system lengths (L = 39 cm). But for smaller system lengths (L = 33 cm) the behavior is inverse. For low magnetic fields the C_{60} oscillation is amplified and the PRI is strongly quenched.

4. Conclusion

By introducing C_{60}^{-} ions into the plasma of the Q-machine the PRI is quenched and in addition an oscillation with a frequency about twice the frequency of the PRI appears. By varying the system length it is possible to distinguish between the 2nd harmonic of the PRI and this C_{60} oscillation. However the latter also shows a linear dependence on the inverse system length. By increasing the magnetic field, the frequency is slightly shifted to lower frequencies and the amplitude decreases while simultaneously the PRI is amplified. Up to now the reason for this behavior is not understood and will be subject of further investigations.

References

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