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COMPARISON OF ECR ION SOURCE PERFORMANCE FOR DIFFERENT MICROWAVE GENERATORS

A. Galata', L. Ciavola, F. Consoli, S. Gammino, S. Marletta

INFN-LNS, Via Sofia 44, 95123 Catania, Italy

Abstract

A complete set of measurements ha been carried out in order to confirm the performances enhancement, previously observed in SERSE source when the cavity is fed by means of a TWT generator instead of a Klystron generator, which ha been commonly used. It was observed that higher extracted currents are produced for higher charge states by using TWT at 14 GHz, while higher extracted currents for every charge state were obtained when the microwaves at 18 GHz are provided to the source. A description of experimental set-up and of the results obtained are given next. The comparison of data will be analysed and an explanation in terms of the current model of ECRIS plasma will be proposed.

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1. INTRODUCTION

The SERSE source at LNS of Catania[1] (fig. 1) is one of the most effective ion sources among those currently working in various laboratories spread over the world, either in terms of extracted currents and in terms of obtained charge states distributions. Many relevant studies on the physics and technology of ECR ion sources have been made possible by the versatility of such a source and in particular the studies upon the role of confining magnetic field and of the frequency for the electromagnetic wave feeding the source, have been completed in 2000[1,2]. As in the recent past[3] an experiment with the room temperature source, CAESAR, has put in evidence the different behaviour of the ECRIS when they are fed by Klystron or TWT generator, a systematic series of measurements was carried out in October 2003 in such a way to have a precise comparison between the performance obtained in the two cases. The comparison regarded both the working frequencies commonly used, 14 and 18 GHz.

At LNS the microwaves needed to heat the plasma electrons can be produced by five different generators:

1) Two SAIREM Klystrons able to generate microwaves with a power up to 2 KW at 14 and 18 GHz.
2) A CPI Klystron able to generate microwaves with a power up to 2 KW at 18 GHz.
3) A Travelling Wave Tube, called TWT1 from now on, able to generate microwaves with a power up to 300 W with the possibility to vary continuously the emission frequency from 8 to 18 GHz. The bandwidth of this generator is about 2 GHz.
4) A Travelling Wave Tube, called TWT2 from now on, able to generate microwaves with a power up to 600 W with the possibility to change continuously the emission frequency from 13,75 to 14,5 GHz. The bandwidth of this generator is about 750 MHz.

Table 1 – *Characteristics of different generators available at LNS.*

Generator	**Emission frequency**	**Maximum power**	**Bandwidth**
Klystron	14; 18 GHz	2 KW	< 100 MHz
TWT1	8-18 GHz	< 300 W	~ 2 GHz
TWT2	13,75-14,5 GHz	< 600 W	~ 750 MHz

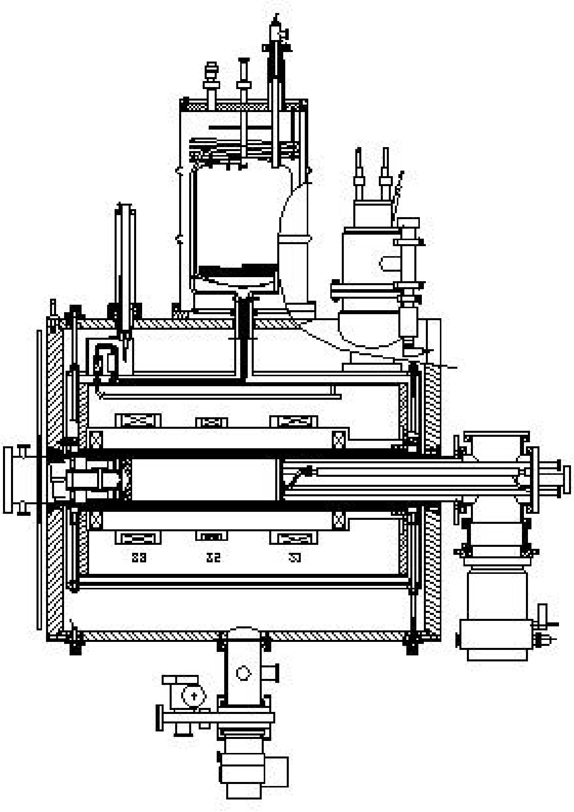

Figure 1 - *The sketch of the SERSE source.*

Some preliminary measurements have been carried out by using the Klystron generators: the charge state distributions have been collected at different power levels for both the working frequencies, by using only the biased disk method and $^{18}O_2$ as working gas (in order to measure fully stripped oxygen beams). The gas mixing was avoided in order to simplify the tests; the working pressure was ~ 10^{-7} mbar while the ion species for which all the parameters were optimised was O^{7+}. Table 2 shows the magnetic field value (Tesla) used at both the working frequencies together with the fields at which ECR resonance occurs; it can be noted that the source works in the so called “High-B mode” at both the working frequency and that the field roughly scales as f_2/f_1.

Table 2 - *Magnetic field values utilized during experiments (Tesla).*

Frequency	B_{ECR}	B_{HEX}	B_{INJ}	B_{MIN}	B_{EXT}
14 GHz	0,5	1,14	2,05	0,35	1,14
18 GHz	0,64	1,41	2,6	0,45	1,52

By reproducing exactly the same experimental conditions (magnetic field values, gas pressure, position and voltage of the biased disk), the spectra at different power levels have been recorded with the TWT1, in order to have a precise comparison with the Klystron at both the working frequencies.

After these comparative measurements, other kinds of tests have been carried out with the TWT 2 at 14 GHz.

2. COMPARISON BETWEEN KLYSTRON AND TWT

The comparative measurements with Klystron (KLY in the figures) and TWT1 at 14 GHz are presented in figure 2. The charge states distributions (CSD) were obtained, respectively, with the Klystron at 250 W and with the TWT1 at 240 W. It can be noted from the figure2 that maximum values for the two distribution are obtained for different charge states (5^+ and 6^+ respectively); moreover, it can be also observed an increase in the extracted currents for the highest charge states. In fact for O^{6+} the extracted current is 1,5 times higher than the one obtained with the Klystron, for O^{7+} it is 2 times higher and for O^{8+} it was increased 8 times or more (6 µA with TWT1, 0,7 µA with Klystron). In other words, figure 2 shows that with the TWT1 we observed an increase in the extracted currents for higher charge states, as greater as higher is the charge state.

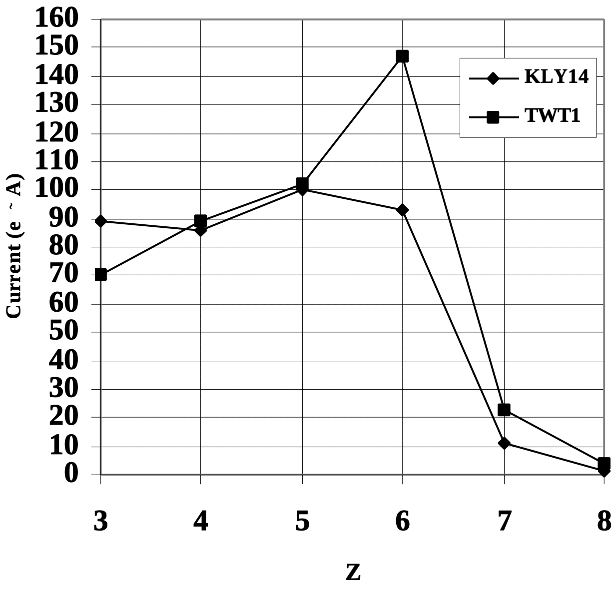

Figure 2 *- Comparison between the CSD of ^{18}O at 14 GHz with KLY at 250W and TWT1 at 240W.*

Since SERSE has been designed to obtain high currents of high charge states, in order to have a measure of the effective gain in power linked to the use of a TWT, in figures 3-5 it is shown the comparison between the trends of higher charge states present in the distribution (O^{6+}, O^{7+}, O^{8+}) with increasing power. In the figures even the preliminary results obtained with the TWT2 are shown. Unfortunately its behaviour above 300 W is not stable and the performance above this threshold were probably affected by such instability.

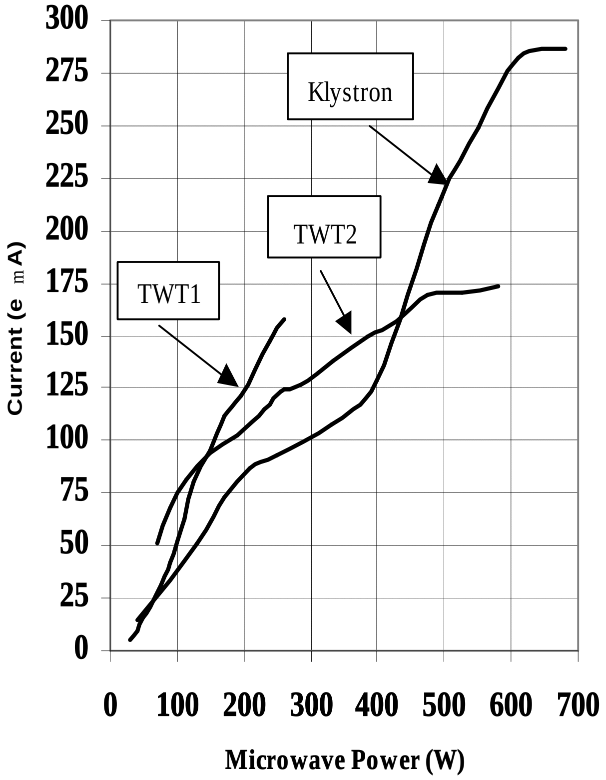

Figure 3 – *Comparison between the of* O^{6+} *current at 14 GHz for Klystron, TWT1 and TWT2, plotted versus rf power.*

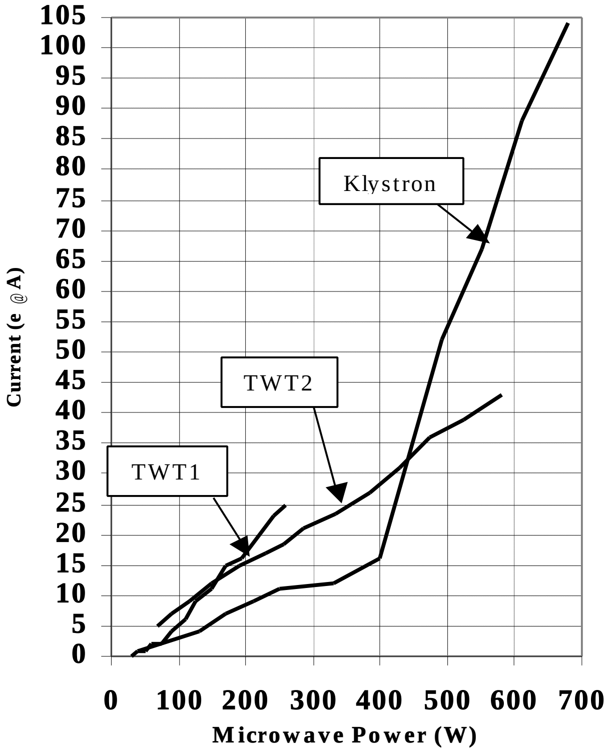

***Figure 4** – Comparison between trends of O^{7+} at 14 GHz for Klystron, TWT1 and TWT2.*

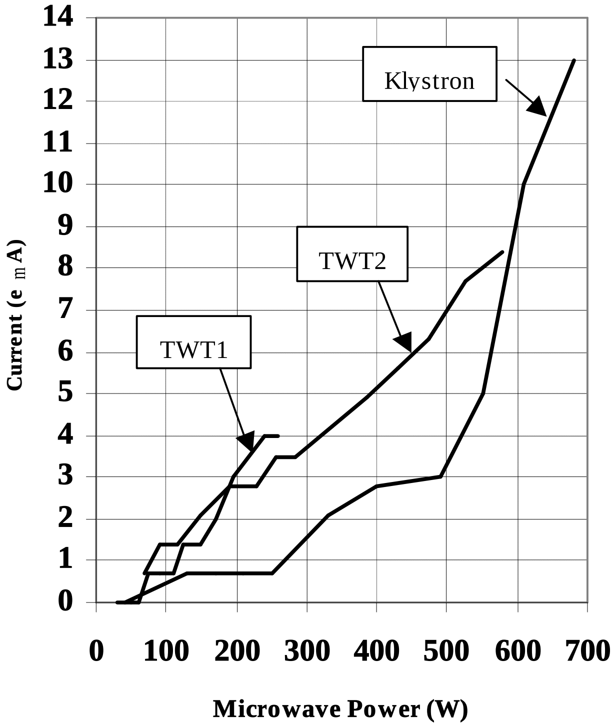

***Figure 5** – Comparison between trends of O^{8+} at 14 GHz for Klystron, TWT1 and TWT2.*

Looking at the previous figures it can be understood that there is a considerable gain in power by using the TWTs: the highest values of extracted currents for O^{6+} and O^{7+}, obtained at 260 W for the TWT1, are obtained with the Klystron at about 450 W with a net gain in power of 1,5 times. Even better is the situation for O^{8+}: 4 μA, already extracted at 240 W with the TWT1, are obtained at more than 500 W with the Klystron with a net gain in power greater than two times. For what concerns the results obtained with TWT2 it can be said that they confirm the results obtained at low power levels but at higher power levels it needs to be checked because it is noted that the performances tend to worsen and become even lower than the ones obtained with the Klystron.

The best results came out from the comparison between Klystron and TWT1 at 18 GHz: in figure 6 the CSD obtained with the Klystron at 190 W and with the TWT1 at 195W are shown. There is a different behaviour with respect to the results observed at 14 GHz: an increase in the extracted current is observed for every ion specie present in the distribution, and the increase was greater as higher was the charge state. The extracted current is 1,1 times the one obtained with Klystron for O^{3+}, 1,3 times for O^{4+}, 1,7 times for O^{5+}, 2,2 times for O^{6+}, 5 times for O^{7+}, concluding with 5,6 μA extracted current of O^{8+}, which charge state was absent in the distribution of the Klystron.

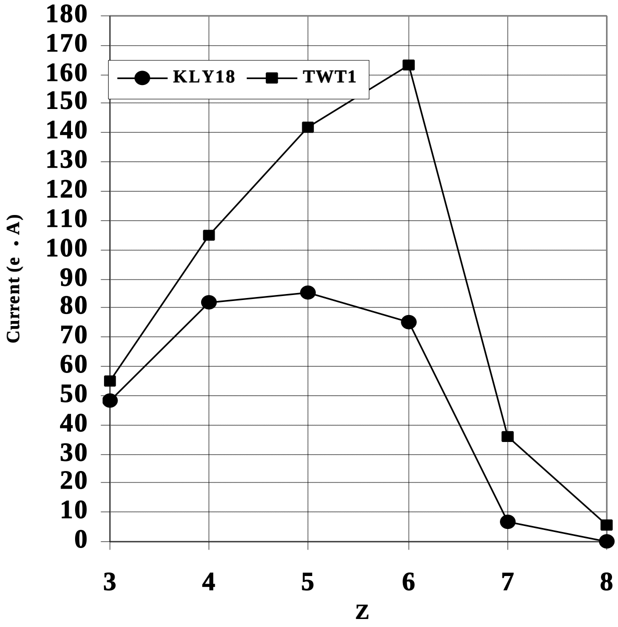

Figure 6 - *Comparison between CSD of* ^{18}O *at 18 GHz with Klystron at 190W and TWT1 at 195 W.*

In figure 7 and 8, the current of O^{7+} and O^{8+} are shown for both the cases. We note that 42 µA of O^{7+} extracted with TWT at 235 W are obtained with Klystron at about 700 W, i.e., at 3 times higher power. For O^{8+} the gain is even more than 3 times: in fact, 9 µA were obtained with TWT at 248 W and with Klystron at a power close to 800 W. This result is particularly appealing for ECRIS operations, as a higher rf power entails a higher plasma chamber heating, leading to an higher pressure, that is detrimental for the build up of the highest charge states. Moreover, some technological aspects are eased by the lower rf power, e. g. the DC break and pressure window lifetime would be increased.

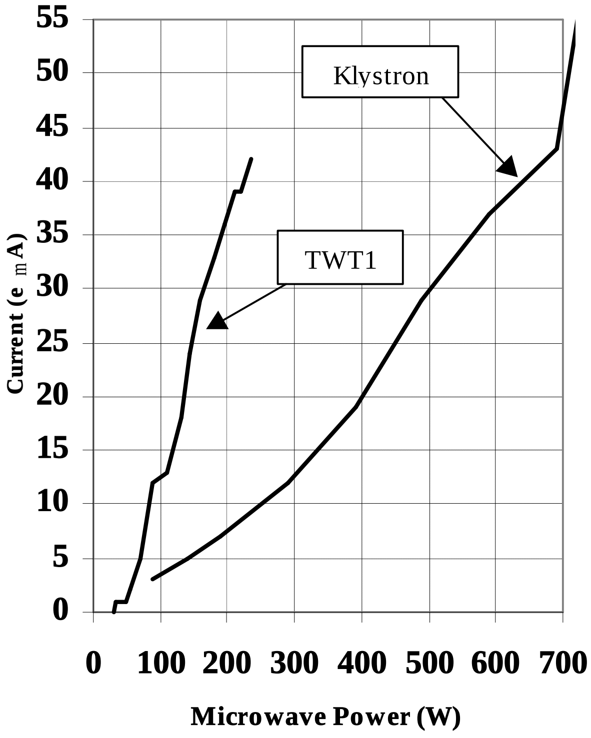

Figure 7 - *Comparison between the of O^{7+} current at 18 GHz for Klystron (up to 700 W) and TWT1.*

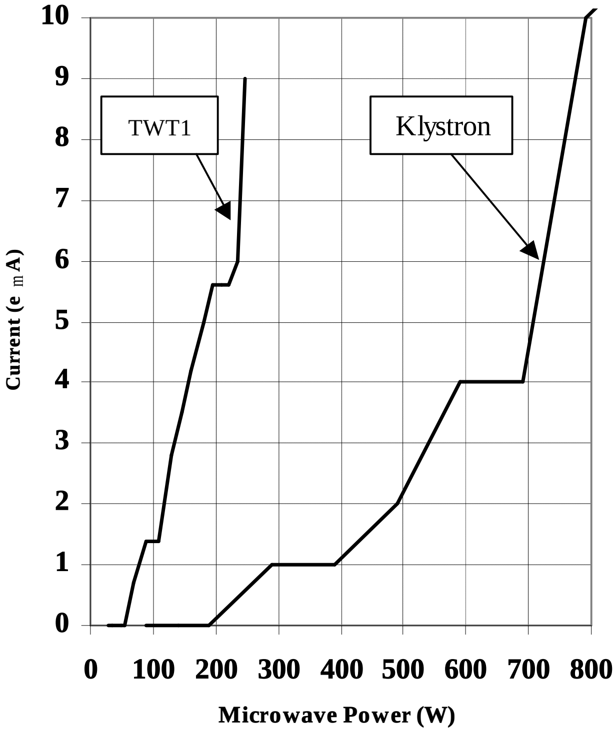

Figure 8 *- Comparison between trends of O^{8+} at 18 GHz for Klystron (up to 800 W) and TWT1.*

3. CONCLUSION

In order to summerize the results obtained from the comparison between Klystron and TWT, it is useful to point out on the highest charge states, i. e. O^{7+} and O^{8+}. It clearly comes out that the TWT generator permits to get at lower power the performance obtained with Klystron at higher power levels. The gain in power, that depends on the charge state and the working frequency, oscillates between 1,5 and more than 3 times for O^{8+} at 18 GHz. Let us try to present a tentative explanation. An increase in electrons temperature and density is evident from the spectra analysis: this increase can be attributed to the large TWT bandwidth because all the other parameters were the same for the two generators., and it can be supposed that the radiation provided by the Klystron is almost monochromatic.

From the study of the propagation of a monochromatic plane wave inside a magnetized plasma, in a direction parallel to the uniform magnetic field and by taking into account the collisions undergone by electrons (without specifying particular kind) by means of a collision frequency ω_{eff}, it can be shown that this plane wave will consist of two circularly polarized waves. Only one of the two has a resonant interaction with the cyclotron motion of the electrons: a typical resonance curve for the velocity of the electrons is shown in figure 9.

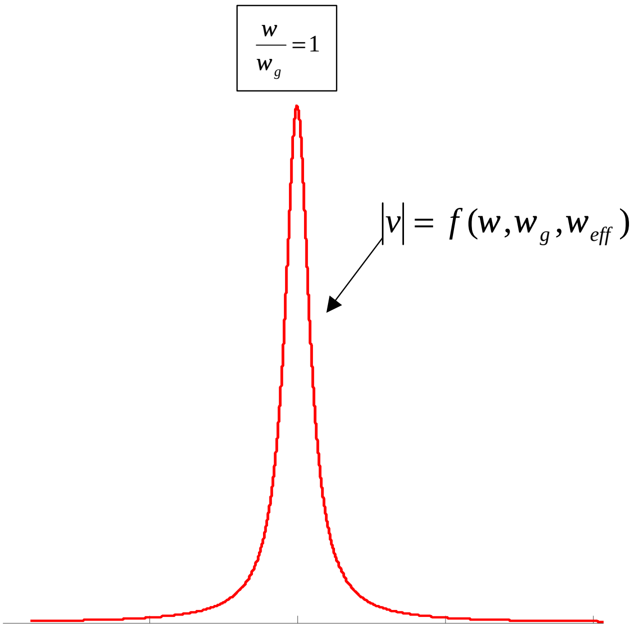

Figure 9 – *Typical resonance curve for electrons' velocity.*

For a quasi collision-less plasma this peak is very narrow: consequently the condition for which electron cyclotron resonance occurs ($\omega = \omega_g$), without taking into account Doppler and relativistic effects or a non uniformity of the magnetic field, will be exactly achieved when electrons pass through the surface (egg shaped)

$$B = B_{ECR} = \frac{2pm_e}{\left|\ _e\right|} u_{EM} \qquad (1)$$

with a gain in energy depending on the electric field’s amplitude and on the duration of interaction. If microwaves with a given bandwidth 2Δω are provided to the cavity and because of the non uniformity of the magnetic field, the condition for a resonant interaction is given not only by (1) but also in any point between the two closed surfaces:

$$B_1 = \frac{2pm_e}{|q_e|}(u_{EM} - \Delta u)\,;\; B_2 = \frac{2pm_e}{|q_e|}(u_{EM} + \Delta u) \qquad (2)$$

as shown in the following figure:

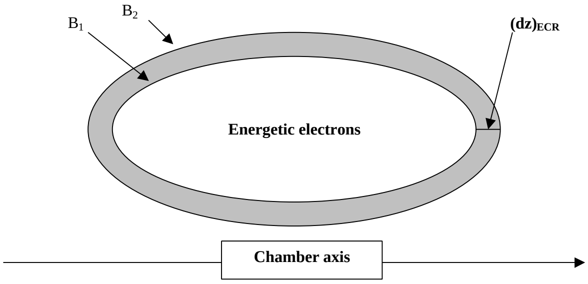

Figure 10 – *Due to generator characteristics resonance occurs in a layer with a certain thickness* $(dz)_{ECR}$.

From what has been said it comes out that, because of electromagnetic waves’ bandwidth, the electron resonance phenomena take place in a volume, instead of a simple surface: and to be precise inside the layer enclosed between the two surfaces B_1 and B_2 (grey part in figure 10). Consequently more electrons can be involved in a resonant interaction with the electromagnetic wave and they can reach also higher energy because, for a given power level, they are subjected to the interaction during the whole time spent by passing through this large resonance zone.

It can be understood that this effect positively influences the performance of the source. For instance the ionisation process is more probable when the number of energetic electrons is larger. Furthermore, we know that the presence of energetic electrons (better confined) in the central part of the chamber creates a negative potential well Δφ with respect to the overall positive plasma potential φ_{plasma}. This effect is qualitatively shown in figure 11.

The higher the number of energetic electrons, the deeper will be the negative well with the TWT. Being the confinement time τ_i of a given charge state z proportional to $\exp(ze\Delta\varphi/KT_i)$, with KT_i equal for every ion species[4], an increase in $\Delta\varphi$ produces a greater increase in τ_i as higher is the value of z. Those results are confirmed by using the second TWT at low power levels, either with the configuration proper for 14 GHz or the one proper for 18 GHz, but we assisted to a lowering in the performances at higher power levels, probably because in this case the generator is observed to be not stable.

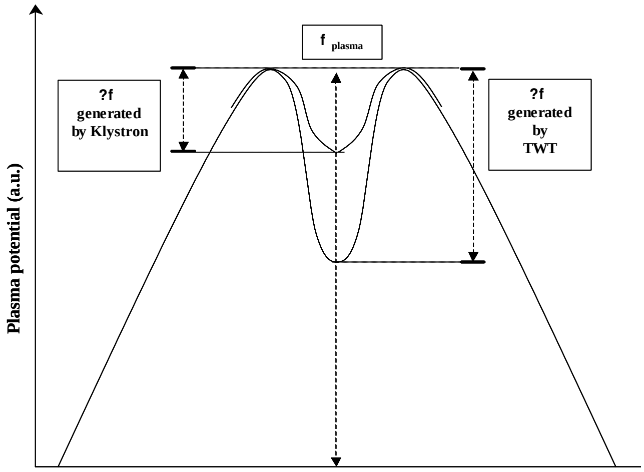

Figure 11 *- The presence of energetic electrons at the centre of plasma creates a negative potential well ?f with respect to the overall positive plasma potential* f_{plasma}. *The larger is the number of energetic electrons, the deeper will be the well.*

Of course, what has been said up to now needs more insight: first of all for what concerns the behaviour of the generator at higher power levels; second, the enlargement of the resonance zone caused by the generator has to be considered together with the one caused by the gradient in the magnetic field and, eventually, by relativistic and Doppler effects which arises at high electrons' energy. Finally, in this paragraph we have given a qualitative explanation, but some quantitative analysis can be available only after a plasma diagnosis, e. g. with a Langmuir probe, that will permit the measurements of the plasma parameters and to determine the structure of the plasma potential, as well as its change with the microwave parameters.

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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