ADVANCES IN ELECTROSTATIC ENERGY ANALYZERS
FOR
ION BEAM PROBE DIAGNOSTIC SYSTEMS

Conference Paper

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INTRODUCTION

The heart of an ion beam probe diagnostic system is a feedback-controlled, electrostatic energy analyzer. This type of analyzer allows for direct measurement of plasma space potential, while providing good noise suppression for density and temperature measurements.

In the past year we have made two significant advances in the design of these analyzers. We have developed a Dual-Gain Analyzer which will enable us to make current density measurements. In addition, we have investigated coupling the feedback signal to the bottom plate of the analyzer instead of the top plate, resulting in increased DC stability as well as better frequency response.

Figure 1 shows a schematic representation of an ion beam probe system. Singly charged primary ions are directed through the plasma, and doubly charged secondary ions are detected by means of the electrostatic energy analyzer. The secondary beam is collected on a split plate detector, with the difference current being amplified and fed back, usually, to the top plate. The standard measurements are the feedback voltage which is a measure of space potential, and secondary ion current which is a measure of $nf(T_e)$.

For linear geometry where we have a purely solenoidal magnetic field, finding the ion trajectories is strictly a two-dimensional problem. However, if current flows in the plasma, the ions will be affected by the B_θ field, resulting in a z displacement of the orbits. The amount of displacement at the detector can be used to extract the current density.

Also shown in the figure is the fact that when the feedback signal is fed back to the top plate of the analyzer, AC coupling must be used (because the feedback voltage is a small correction which must be added to a large DC voltage). This results in poor DC stability for space potential measurements, and will eventually degrade the frequency response of the entire analyzer system.

The problems associated with measuring current density are illustrated in Figure 2. The general technique is to extract the current density from the magnetic field generated by the current flow. For a solenoidal confining field, the dispersion of the z-momentum of the secondary ions is related to the value of B_0 at the point where the secondary ions were created. Thus, the basic objective is to measure v_z , which is usually done by measuring a time-of-flight displacement. However, as shown in the bottom figure, any displacement measured at the detector location depends on both the z component of velocity and the initial displacement of the beam when it enters the detector region. Thus, a simple measurement of H does not yield v_z .

Figure 3 shows how to overcome this problem. In practice, instead of measuring a displacement of a beam, one would pass the beam through a pair of deflection plates and measure the voltage required to center the beam on a detector which is placed after a drift region. The voltage required is determined by h , v_z , and the length of the drift region. If two drift regions were used, each with its own detector, two different voltages would be measured. As long as the length of the drift regions is known, these two voltages may be used to extract both the initial displacement h , and the desired v_z . This has led to what we call a Dual Gain Analyzer.

Figure 4 schematically shows the Dual-Gain Analyzer. For the drift regions, we use two paths through a standard electrostatic energy analyzer. There are two sets of detector plates which are split in the x direction for measuring space potential, and split in the z direction for measuring current density. The difference current from the z plates is amplified and fed back to a pair of z deflection plates, located near the entrance slit of the analyzer to measure current density. The difference current from the x plates is amplified and fed back to the top plate to measure space potential. To switch from one detector set to the other, the DC voltage on the analyzer, V_a , is changed. Since the geometric gain of the analyzer is determined by V_a/V_0 (V_0 is the gun voltage), there will be a different geometric gain for each measurement; thus, the name Dual-Gain Analyzer.

Such an analyzer has been constructed and we are presently performing preliminary tests. It should be possible to detect current densities of the order of 100 A/cm^2 , with simultaneous measurements of space potential and density with the usual accuracy. However, as we have mentioned in previous years, the extraction of the current density is certainly not a trivial problem.

As mentioned earlier, the AC coupling necessary for an analyzer where the feedback voltage is fed back to the top plate of the analyzer results in poor DC stability and also limits the frequency response of the detector system. We have attempted to overcome these problems by coupling the feedback signal to the bottom plate of the analyzer. The concept is shown schematically in Figure 5.

The secondary beam enters the analyzer at some angle θ . As the beam is swept along a detector line in the plasma, this entrance angle changes, resulting in a correction that must be made in the space potential measurements. To minimize this correction, one usually uses a field free drift region below both the entrance and exit slits, with the detector placed at an appropriate angle. (Thus both of the bottom plates are normally at ground potential). What we have done is to couple the feedback signal to one of these plates. Since this plate is nominally at ground potential, the feedback signal can be DC coupled to the plate, resulting in good DC stability. The frequency response will also be improved since the AC coupling mechanism has been eliminated.

However, the effect of this bottom coupling is to create an electric field in what used to be a drift region. Thus, the angle α at which the beam enters the analyzer will be different from the angle θ at which the beam entered the entrance slit. This results in a much more complicated voltage correction function.

This is shown more clearly in Figure 6. For a top-coupled analyzer, the space potential ϕ can be related to the feedback voltage V_b and the gun voltage V_o . θ is the angle at which the beam enters the analyzer and β is the design angle for the analyzer. However, the effective gain of the system $G_T(\theta, \beta)$ is nearly independent of θ , and thus, the effective gain is essentially equal to A_g , the geometric gain of the analyzer. $f(\theta, \beta)$ is what we have presented before as the voltage correction function, which is minimized by choosing a design angle of 32° .

For a bottom coupled analyzer, the space potential may also be related to the feedback voltage V_b and the gun voltage V_o . However, the effective gain of the bottom coupled analyzer, $G_B(\theta, \beta)$ is a strong function of the entrance angle. Thus, the gain of the system changes as the beam is swept along a detector line.

This is shown more clearly in Figure 7. Here we have plotted the effective gain for both top and bottom coupled analyzers as a function of the change in entrance angle θ from the design angle β . The design angle was chosen to be 32° and the physical dimensions chosen resulted in geometric gains of 3 and $4 \frac{1}{3}$. For the top coupled analyzer, the effective gain is constant and equal to the geometric gain. For the bottom coupled case, however, there is a significant change in the effective gain as the entrance angle changes. Note that even when $\Delta \theta = 0$, the effective gain is not equal to the geometric gain. (The effective gain of a bottom coupled analyzer is negative because a positive voltage applied to the top plate of the analyzer increases the field, whereas a positive voltage applied to the bottom plate decreases the field).

Figure 8 shows the detailed plots of space potential versus feedback voltage for both top and bottom coupled analyzers. The design angle is 32° , the geometric gain is 3, and the gain voltage is 40 KV for both cases. Each line represents a different entrance angle θ . For the top coupled analyzer, the lines all have the same slope, which is given by the geometric gain A_g . For the bottom coupled analyzer, the slope of each line corresponds to the effective gain for that particular value of

9. Thus, each line has a different slope. This makes handling the data a little more complicated, but this is the price paid for the better DC stability and improved frequency response.

CONCLUSION

We have discussed two new concepts for feedback controlled electrostatic energy analyzers; a dual gain analyzer for current density measurements, and bottom plate coupling to provide DC stability and better frequency response. We have built an analyzer incorporating both of these concepts and are about to begin preliminary measurements of its performance. These measurements will be reported at a later time.

(1)

(2)

(3)

(4)

VOLTAGE CORRECTION FUNCTION

Top Coupled

$$\phi = G_r(\theta, \beta) V_0 + f(\theta, \beta) V_1$$

$$= A_r V_0 + f(\theta, \beta) V_1$$

Bottom Coupled

$$\phi = G_b(\theta, \beta) V_0 + f(\theta, \beta) V_1$$

G = strong function of θ, β

(6)

(5)

(7)

(8)