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K1200 Stripper Foil Mechanism RF Shielding

Introduction

This paper describes the process used to design effective rf shielding for the K1200 foil changing mechanism. Some postulates will also be made in an attempt to offer some explanations for the unexpected observation of fields existing within the dees even when tuned to the condition of mid-plane symmetry.

For background, this facility is currently in the final stages of an upgrade that aims to couple the two cyclotrons (K500 to K1200) together. The upgrade is intended to increase the number and intensity of secondary exotic beams (radioactive short lived isotopes) available for experiments. The secondary beams are created by fragmentation of the primary beam. The technique utilizes high current, low charge state ion beams readily available from an ECR (Electron Cyclotron Resonance) source to be axially injected and accelerated in the K500 and then extracted and guided to the K1200 to be radially injected and post accelerated. To begin stable post acceleration, the beam must be matched to the K1200 by stripping the ions to the appropriate higher charge state at the proper cyclotron radius. The resultant high intensity and high energy beam extracted from the K1200 cyclotron is then incident on a fragmentation target. Fragments are then projected into a fragment separator based on a magnetic chicane to select the species of interest. The selected species is then guided through a magnetic switchyard to the desired experimental area. The described system imposes two new operations for this laboratory consisting of 1) radial injection of a high intensity rf structured beam and 2) reliable continuous extraction of a high intensity beam.

A fundamental and complex component needed to increase the ion charge state for this operation is a target foil within the K1200 at the right injection radius. Since the foil has a finite lifetime, it is desirable to have a foil changing mechanism that can facilitate changing the foils without breaking vacuum. A foil changing mechanism with the aforementioned properties has been constructed and installed within the rf electrode designated as the “C dee” of the K1200 cyclotron. Unfortunately, the rf field within the dee is not zero, and the preliminary rf test with the foil changer caused some components to overheat and be damaged.

The K1200 has 3 dees each of which can sustain external rf potentials in excess of 160 KV peak from 9.5 to 26.5 MHz. Although the inside of each dee can be described as “field free”, the tacit assumption that “field free” means zero is not valid. For example 0.1% of the peak field can be considered “field free”, however, at 160 KV this amounts to 160 Volt peak potentials. The associated fields at this level can easily heat materials with poor rf properties. The foil changer is constructed of materials that optimize strength, accuracy, and magnetic properties versus materials that reduce rf losses.

To reduce the rf fields within the dee so that the foil changing mechanism can function reliably, we designed and installed compatible rf shielding on the surface of the dee facing the beam plane and suitable rf instrumentation to measure the shielding effectiveness. The measurements of the shielding effectiveness were made using ratio-metric techniques.

Measurement Techniques and Apparatus

The foil changing mechanism is installed in the lower dee shell of the C dee as shown in figure 1. Thirty-two foils are equally spaced on foil holders distributed around the mechanism on a chain. Only the foil closest to the cyclotron center is “popped-up” to intercept the beam. When a foil is no longer useable, it is replaced by moving the chain to the next foil position. To properly position the active foil with respect to the injected ion beam, the entire foil changer may be moved such that “Pin C” can be placed at any location within the “Region D”, while the rear of the mechanism is guided by “Pin A” rigidly mounted to the dee through “Slot B” in the foil changer. The movement is accomplished via actuating hydraulic cylinders within the dee using water as the hydraulic fluid. The changer is shown in the assumed worst-case position for rf pick-up.

Figure 2 shows the same lower dee with the full final compliment of shields, straps, and sensors. The shielding was developed by replacing the foil changer with two approximately 4 inch square plates to be used as rf sensors. The plates rest on supporting insulators and are placed at approximately the same vertical level as the foil changer. One plate was placed near the inner cyclotron radius of the area traversed by the foil changer and the other near the outer cyclotron radius of this area. A twisted pair of leads is connected between each plate and the inner surface of the dee in near proximity to the supporting insulator base. The leads are connected to the pins of a vacuum feed through connector. The pins on the air side of the feed through are connected to twisted pair cabling that carries the signals along the inside of the inner conductor of the coaxial dee tuning stems. (It was verified that the leads do not pick up signals due to the path traversed.) From the dee stem exit, they are then transferred to high quality 50 Ohm coaxial cables that guide the signals to a location where they are terminated in 50 Ohms and instrumentation exists to make the measurements. The measurements were made with a Tektrionics model TDS 224 oscilloscope.

Using the apparatus described, a baseline measurement with no shielding was made followed by a sequence of systematically increasing the shielding and retaking the measurement. The measurements were made at the same displayed dee voltage without disturbing the sensors or instrumentation between steps. Using this technique, the ratio of the data between steps is used as a measure of the gain or attenuation of the change made. With the exception of the two final measurements, all of the measurements were made at **20.3 MHz** and **35 KV** peak displayed dee voltage. The step-by-step results are tabulated in the Data section of this report that follows.

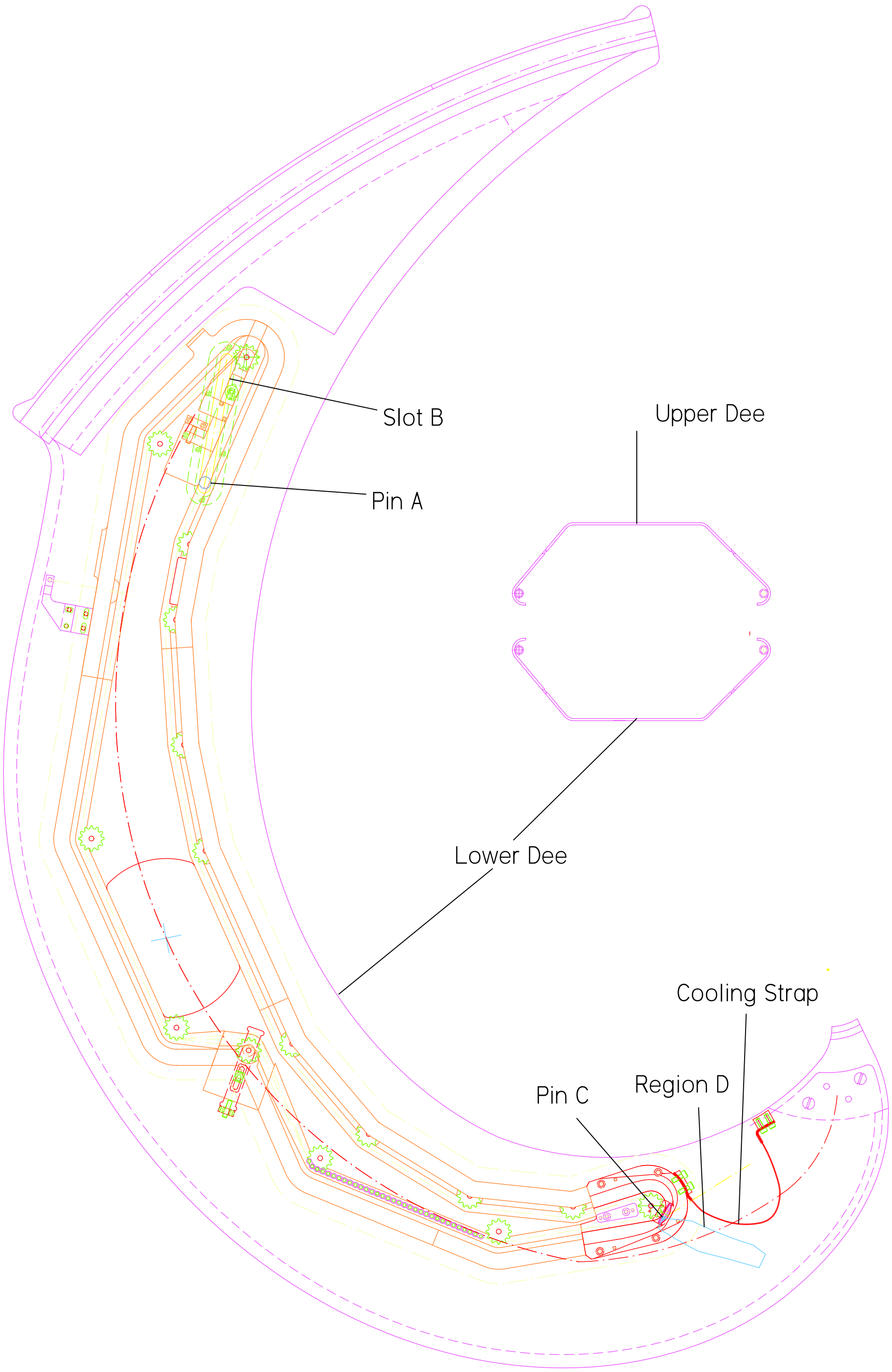

Figure 1
The Lower Dee shell and Foil Changing Mechanism

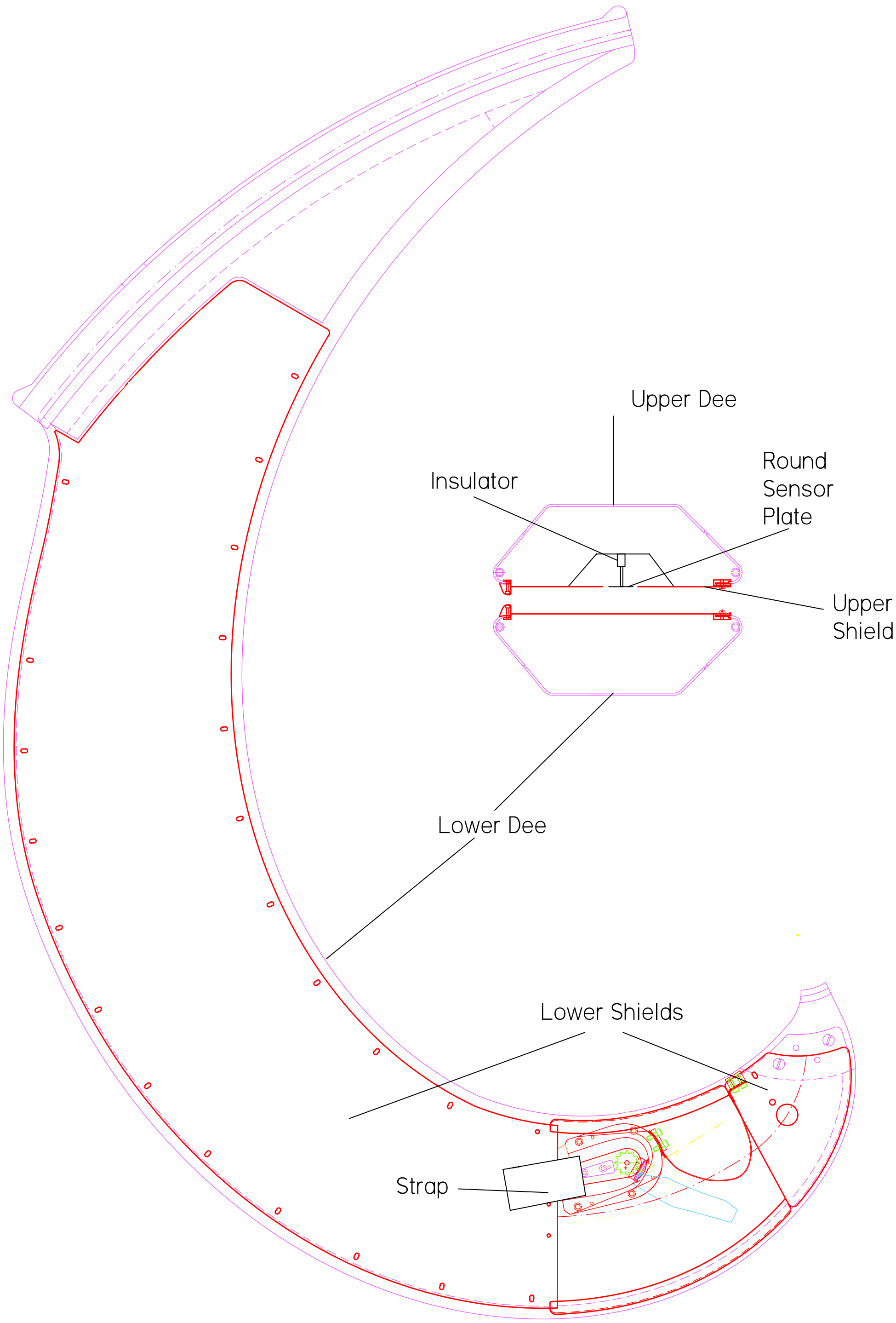

Figure 2
The Shielding and RF Sensor

Data

"*" denotes the data was not available for this case.

Baseline Measurement with no Shields or Strap										
Stem Imbalance						Inner Plate			Outer Plate	
Pot (Volts)	Stem (inches)	Displayed Dee Voltage (kV peak)		Symmetry Probe (Vrms)		Plate Voltage (Vrms)	Temperature Change (Deg. C)		Plate Voltage (Vrms)	Temperature Change (Deg. C)
-0.26	-3.9	35		*		18.5	*		8.5	*
0	0	35		*		21.5	*		12.5	*
0.22	+3.3	35		*		23.5	*		15.2	*

Case 1
The results for no shielding

Measurement with Lower Shield and no Strap										
Stem Imbalance						Inner Plate			Outer Plate	
Pot (Volts)	Stem (inches)	Displayed Dee Voltage (kV peak)		Symmetry Probe (Vrms)		Plate Voltage (Vrms)	Temperature Change (Deg. C)		Plate Voltage (Vrms)	Temperature Change (Deg. C)
-0.26	-3.9	35		*		17.9	*		3.55	*
0	0	35		*		20	*		2.9	*
0.22	+3.3	35		*		22.2	*		2.38	*

Case 2
The results with the lower shield added

Measurement with Lower Shield and Strap										
Stem Imbalance						Inner Plate			Outer Plate	
ot (Volts)	Stem (inches)	Displayed Dee Voltage (kV peak)		Symmetry Probe (Vrms)		Plate Voltage (Vrms)	Temperature Change (Deg. C)		Plate Voltage (Vrms)	Temperature Change (Deg. C)
-0.26	-3.9	35		*		9.4	*		1.08	*
0	0	35		*		0.462	*		0.056	*
0.22	+3.3	35		*		8.5	*		0.974	*

Case 3
The results with the lower shield and strap added

Measurement with Lower and Upper Shield and Strap										
Stem Imbalance						Inner Plate			Outer Plate	
Pot (Volts)	Stem (inches)	Displayed Dee Voltage (kV peak)		Symmetry Probe (Vrms)		Plate Voltage (Vrms)	Temperature Change (Deg. C)		Plate Voltage (Vrms)	Temperature Change (Deg. C)
-0.26	-3.9	35		1.67		8.92	*		1.05	*
0	0	35		0.001		0.02	*		0.015	*
0.22	+3.3	35		1.48		8	*		0.909	*

Case 4
The results with an upper shield added to case 3.

Measurement with Upper Shield and Foil Changing Mechanism

Stem Imbalance						Inner Plate			Outer Plate	
Pot (Volts)	Stem (inches)	Displayed Dee Voltage (kV peak)		Symmetry Probe (Vrms)		Plate Voltage (Vrms)	Temperature Change (Deg. C)		Plate Voltage (Vrms)	Temperature Change (Deg. C)
-0.26	-3.9	35		0.914		9.58	*		10.6	*
0	0	35		0.086		4.24	*		8.25	*
0.22	+3.3	35		0.702		16.8	*		5.86	*

Case 5

The sensors are replaced with the actual foil changing mechanism,
only the upper shield is retained.

Measurement with All Shields, Strap, and Foil Changing Mechanism

Stem Imbalance						Inner Plate			Outer Plate	
Pot (Volts)	Stem (inches)	Displayed Dee Voltage (kV peak)		Symmetry Probe (Vrms)		Plate Voltage (Vrms)	Temperature Change (Deg. C)		Plate Voltage (Vrms)	Temperature Change (Deg. C)
-0.26	-3.9	35		1.59		2.55	*		0.048	*
0	0	35		0.032		0.109	*		0.005	*
0.22	+3.3	35		1.48		1.98	*		0.08	*

Case 6

The results for the actual foil changing mechanism fully shielded.

Measurement with All Shields, Strap, and Foil Changing Mechanism, 26.5 Mhz										
Stem Imbalance						Inner Plate			Outer Plate	
Pot (Volts)	Stem (inches)	Displayed Dee Voltage (kV peak)		Symmetry Probe (Vrms)		Plate Voltage (Vrms)	Temperature Change (Deg. C)		Plate Voltage (Vrms)	Temperature Change (Deg. C)
-0.12	-1.8	35		2.46		2.81	2.5		0.295	1
0	0	35		0.113		0.147	0		0.116	0
0.04	+0.6	35		0.961		0.741	1		0.044	1

Case 7

The results for case 6 at the assumed worst-case frequency of 26.5 Mhz

Complete Foil Mechanism with Popped up foil, complete shielding, 26.5 Mhz										
Stem Imbalance						Inner Plate			Outer Plate	
Pot (Volts)	Stem (inches)	Displayed Dee Voltage (kV peak)		Symmetry Probe (Vrms)		Plate Voltage (Vrms)	Temperature Change (Deg. C)		Plate Voltage (Vrms)	Temperature Change (Deg. C)
-0.12	-1.8	35		2.21		1.39	4		1.55	1
0	0	35		0.008		0.395	0		0.025	0
0.12	+1.8	35		2.43		0.719	4		1.6	1

Case 8

The results for case 7 with a popped-up foil at 26.5 Mhz

Qualitative Analysis and Postulates

The data tabulated in the previous sections shows that as the shielding was increased and the remaining exposed surfaces tied to these shields, the rf field on the foil changing mechanism dropped substantially. An E-field probe has confirmed that electric symmetry occurs when the rf tuning stems are symmetric. This condition is referred to as “mid-plane symmetry”. It can also be seen by comparing case 3 to case 4 that when the upper shield was added the fields were substantially reduced further even under conditions of mid-plane symmetry. It is now apparent that without shielding, rf fields will exist within the dees even with symmetric tuning. The ensuing discussion in this section seeks to explain these results.

A combination of the complex geometry and large size with respect to the rf wavelength of the K1200 dees makes it a difficult and time consuming proposition to try and get an exact quantitative solution to the fields inside the dees. It has been assumed that if the tuning stems attached to the upper and lower dee shells were adjusted to be electrically symmetric (referred to as mid-plane symmetry), that the fields within the dees would drop to zero very close to the beam entrance and exit gaps. It now appears that even with mid-plane symmetry that the fields, although sometimes minimized, are not eliminated. The question is then why?

I postulate that some amount of current is traversing the interior of the dee shells even when mid-plane symmetry conditions are met. This is likely due to the spiral shape of the dee causing it to appear as a curved transmission line with the inner conductor (dee) sliced through and separated along the curve. The internal inductance of the dee interior then causes an electric field (“**induction field**”) to be established. Because the currents enter the upper and lower dee shells with the same spatial and temporal polarity (a cool way to say phase!) but are bent in opposite directions into the interior, the resultant induction fields in each dee shell oppose each other. Thus when the interior contents of the dee shells are identical, no net induction field exists and an rf E-field probe would not yield a signal due to this phenomena.

The E-field probe measures the total resultant electric field that apparently is the sum of the field due to asymmetric tuning of the stems (“**asymmetry field**”) with the induction field. The polarity of the induction field does not change based on the net direction from center the tuning stems are adjusted while the asymmetry field does. As mentioned previously, with identical upper and lower surfaces about the beam plane no net induction field would be measured. However, with non-identical dee shell contents, one direction from center of tuning stem asymmetry would have the induction fields and asymmetry fields adding to each other while the other direction from center would have them subtracting from each other. This would lead to an rf E-field probe finding an artificial field minimum for some asymmetric tuning stem position. This is the situation that has been measured previously when the electric field probe was used in the dees that included a cryopanel in the lower dee shell and an empty upper dee shell. This situation led one to believe that large offsets from mechanical symmetry of the tuning stems were needed to minimize the rf fields within the dees: that ,for the record, is not the case and not a good thing to do.

Concluding Remarks and Recommendations

Fields exist in the interior of the K1200 dees even when the stems are tuned symmetrically. The fields are a sum of the "asymmetry field" due to asymmetric mechanical positioning of the tuning stems and the current induced "induction field" likely due to the spiral shape of the dees. These fields can be substantially minimized by symmetric tuning of the stems and installation of rf shields on the dee surfaces facing the median plane. By forcing the upper and lower dee surfaces facing the beam plane to be identical, an E-field probe properly connected accurately measures E-Fields due to any sort of asymmetric conditions.

We recommend that all dees have an upper shield installed with an integral E-field probe as was done on the C dee. We also recommend that the A and B lower dees that contain the cryopanels have multiple 2 to 4 inch straps bridge the sides of the dee in a manner that does not significantly degrade vacuum pumping yet provides proper symmetry for the E-field probe. Not only will this allow us to verify symmetric conditions, but may also remove some heat load from the cryopanels.

A two step process is recommended for implementing the foil changer shields. As a first step, the shields should be made to allow the changer to traverse through all of the necessary space yet not be concerned with replacing the foil magazine under vacuum. The second step shields would be enhanced to allow for changing the foil magazine under vacuum. It is recommended that this approach be taken so that radial injection studies of the K1200 can begin as soon as possible.

As a final note, these E-field probes may also yield detectable signals from the beam and may prove useful for beam diagnostics as well.