



TECHNISCHE
UNIVERSITÄT
WIEN

Project Report

Preliminary research on an electron beam setup for the QUAK experiment

performed at Atominstitut



at Technische Universität Wien
Faculty of Physics

under the supervision of
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and
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¹ 1 Short introduction to QUAK

² The goal of QUAK (quantum klystron) is to drive Rabi oscillations between hyperfine
³ levels of ^{39}K which has a frequency of 461.7 MHz [tiecke:potassium-properties]
⁴ using a classical electron beam. For this, it is necessary to Doppler cool the atoms in
⁵ a MOT (magneto-optical trap) using lasers. Once the atoms are trapped, they will
⁶ be exposed to the near-field of the electron beam, which will be spatially modulated
⁷ with the transition frequency. In order to achieve this goal, the beam must allow
⁸ for a current of 100 μA . The goal of QUAK (quantum klystron) is to drive Rabi
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¹¹ to Doppler trapped, they will be exposed to the near-field of the electron beam, which
¹² will be spatially modulated with the transition frequency. In order to achieve this goal,
¹³ the beam must allow for a current of 100 μA and a beam waist of 100 μm .

¹⁴ In our work, we conducted first experiments on how to accomplish an electron beam
¹⁵ fulfilling those requirements.

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2 Cathodic Ray Tube Basics

This section features a quick explanation what a CRT is and what its main components are, followed by a more detailed description on how these components are implemented in the CRT Heerlen D14-363GY, which was used in this project. It ends with a description of the important characteristics of the CRT and the requirement the theory poses on them. This chapter features a quick explanation what a Cathodic Ray Tube (CRT) is and what its main components are. This is followed by a more detailed description on how the individual components are implemented in our used CRT, a Heerlen D14-363GY. The chapter ends with a description of the important characteristics of the CRT and the requirement the theory poses on them.

2.1 Underlying Physics

Wikipedia states: “The cathode-ray tube (CRT) is a vacuum tube that contains one or more electron guns and a phosphorescent screen and is used to display images. It modulates, accelerates, and deflects electron beam(s) onto the screen to create the images.”

Wikipedia states: “The cathode-ray tube (CRT) is a vacuum tube that contains one or more electron guns, while a phosphorescent screen and is used to display images. It modulates, accelerates, and deflects electron beam(s) onto the screen to create the images.”

There are three vital components to accomplish this feat: the electron gun, the electron lens and the deflection plates.

The electron gun generates free electrons from a cathode material, accelerates them onto an anode and thereby produces an electron beam (see fig. 2.1). One important characteristic in the selection of a cathode material is a low work function. It denotes the amount of energy needed to extract one electron from the material. There are two ways to overcome this energy barrier in an electron gun; one can either apply a strong electric field (“field emission”, “cold cathode”) as seen in fig. 2.2b. Or one can heat the material until some electrons have enough thermal energy to overcome the energy barrier (“thermal emission”, “hot cathode”, fig. 2.2a).

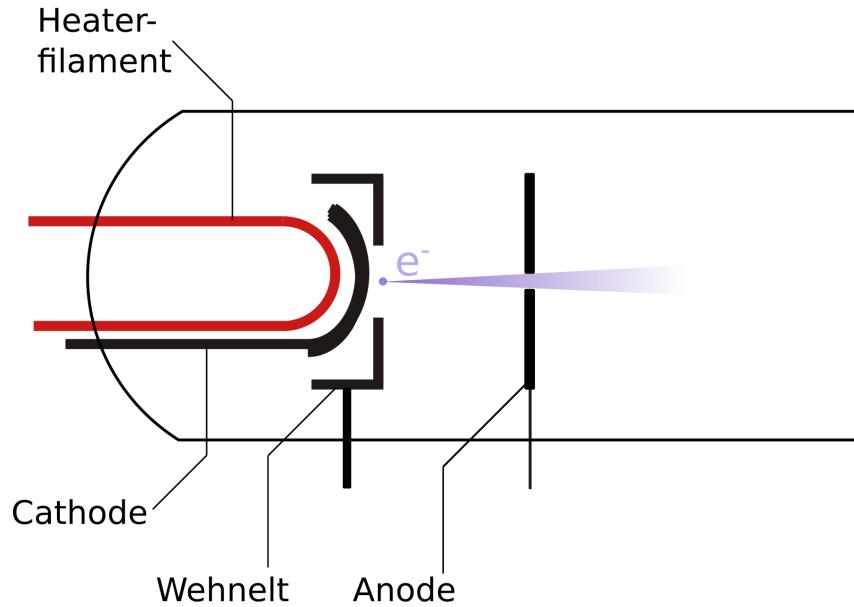
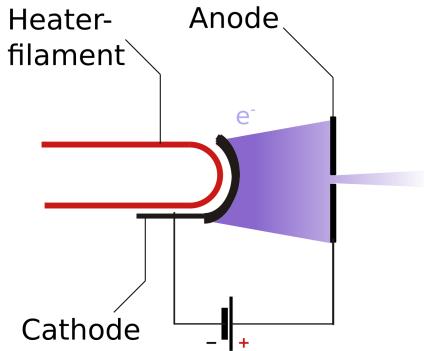


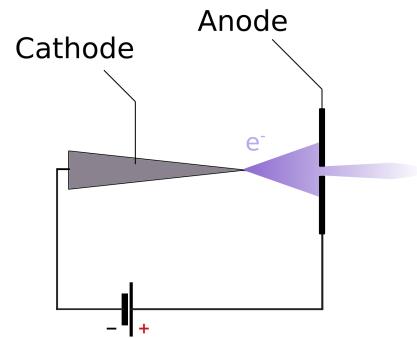
Figure 2.1: Schematic of an electron gun

1 The electron gun extracts electrons from a cathode material, accelerates them onto
 2 a perforated anode and thereby produces a free electron beam (see fig. 2.1). One
 3 important characteristic in the selection of a cathode material is a low work function.
 4 It denotes the amount of energy needed to extract one electron from the material.
 5 There are two ways to overcome this energy barrier in an electron gun; one can either
 6 overcompensate it by applying a strong electric field (“field emission”, “cold cathode”,
 7 fig. 2.2b); or one can heat the material until some electrons have enough thermal energy
 8 to overcome the energy barrier (“thermal emission”, “hot cathode”, fig. 2.2a). For our
 9 CRT, only thermal emission is relevant, more detail on this will be added later along
 10 with the description of our cathode’s design. For our CRT uses a hot cathode, more
 11 detail on this will be added later along with the description of our cathode’s design.

12 The cathode itself is housed in a so-called Wehnelt cylinder, as the name suggests
 13 it is conducting cylinder which is set to a slightly more negative potential than the
 14 cathode itself. This part implements two features; firstly it condenses the emitted
 15 electrons, leading to a smaller spot size, i.e. making the cathode a more point-like
 16 electron source. Secondly it enables us to regulate the beam current, the more negative
 17 the Wehnelt potential is, the less electrons are emitted by the electron gun. As we make
 18 the Wehnelt potential more positive, the beam current increases and continues to rise
 19 even after it is more positive than the cathode itself. However the spot size reduction



(a) Schematic of a hot cathode



(b) Schematic of field emission cathode

Figure 2.2: Cathode types

is lost in the process, along with the ability to properly focus the beam with electron optics. Normally the cathode itself is covered in beam direction in a so-called Wehnelt cylinder. Which is a conducting cylinder set to a slightly more negative potential than the cathode. This part implements two features; firstly it condenses the emitted electrons, leading to a smaller spot size, i.e. making the cathode a more point-like electron source. Secondly it enables us to regulate the beam current, the more negative the Wehnelt potential is, the less electrons are emitted by the electron gun. As we make the Wehnelt potential more positive, the beam current increases and continues to rise even after it is more positive than the cathode itself. However, the spot size gets increased, while the proper beam focus is lost.

The electrons ,that leave the electron gun, are still divergent and need to be focused. For our 2 keV electrons an electrostatic lens is used. In the simples way these are cylindrically symmetrical pieces of conductor, like a ring or tube, set to an electrical potential. By combining several of them, one can (theoretically) engineer an electro-optical system with any combination of desired focal lengths f_1 and f_2 .

The electrons that leave the electron gun are still divergent and need to be focused. For our 2 keV electrons it is still possible to use an electrostatic lens. Cylindrically symmetrical pieces of conductor, like rings and tubes, can be set to an electrical potential and act as a lens for the electrons. By combining several of them, one can (theoretically) engineer an electro-optical system with any combination of desired focal lengths f_1 and f_2 . The field of this system is simply governed by Laplace's equation in cylindrical coordinates: The field of this system is simply governed by Laplace's

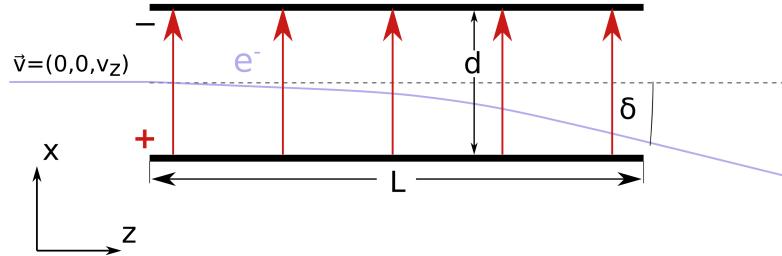


Figure 2.3: Deflection of an electron beam in a constant electrical field

¹ equation in cylindrical coordinates:

$$\frac{1}{r} \frac{\partial \phi}{\partial r} + \frac{\partial^2 \phi}{\partial r^2} + \frac{\partial^2 \phi}{\partial z^2} = 0 \quad (2.1)$$

² If we take the axis of the beam to be the z-axis, the focal point position in the x-y-plane
³ can be shifted using the two pairs of deflection plates, one for the x- and one for the
⁴ y-direction. The deflection is achieved by applying a voltage between the two parallel
⁵ plates. (see: fig. 2.3) By starting with an electron with kinetic energy $e \cdot U_0$ which
⁶ is accelerated in x-direction by a constant force $e \cdot U_x/d$ over the extent of the plates
⁷ L , the deflection angle is approximately [Demtroeder3]: If we take the axis of the
⁸ beam to be the z-axis, the focal point position in the x-y-plane can be shifted using
⁹ two pairs of deflection plates, one for the x- and one for the y-direction. The deflection
¹⁰ is achieved by applying a voltage between the two parallel plates. (see: fig. 2.3) For an
¹¹ electron with kinetic energy $e \cdot U_0$, which is accelerated in x-direction by a constant
¹² force $e \cdot U_x/d$ over the extent of the plates L , the deflection angle δ is approximately
¹³ [Demtroeder3]:

$$\delta \approx \tan(\delta) \approx \frac{U_x \cdot L}{2U_0 \cdot d} \quad (2.2)$$

¹⁴ For the measures of our CRT ($L \approx 10$ cm, $d \approx 1$ cm, $U_0 \approx 2$ kV and distance to
¹⁵ screen ≈ 20 cm) this amounts to a deflection coefficient of around 20 V cm^{-1} , which is
¹⁶ quite consistent with the value given in the CRT's manual.

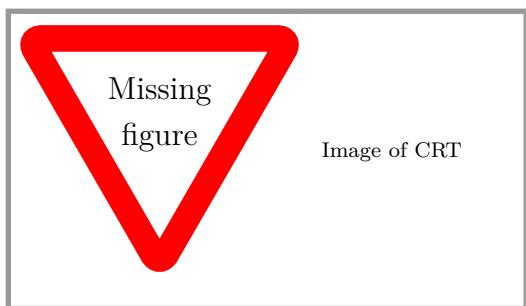
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2.2 Implementation in the Heerlen D14-363GY

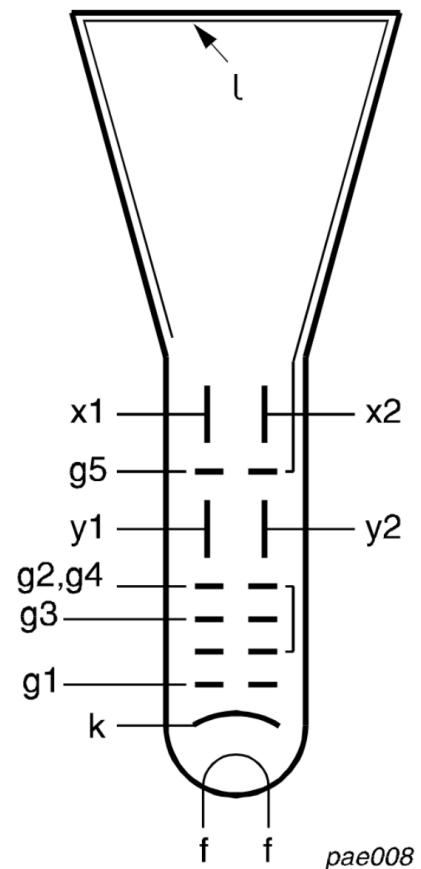
This section describes how the mechanisms described above are implemented in the CRT that was used in this project: the PDS/CRT Heerlen D14-363GY. Figure 2.4a shows an image of said CRT, fig. 2.4b shows a schematic depiction. The cathode is not visible, as it is fixed inside the Wehnelt cylinder (1), just a few millimeters from the exit of the wehnelt cylinder the electrons pass through the perforated anode (2) they gain their full final kinetic energy over this short distance. The electrons that go through the perforation and enter the electrostatic lens, have 2 keV and therefore move at a speed of approximately $0.08c$. The electrostatic lenses are realized using three conducting rings (3), that are set to the same potential but have varying radii: Each consecutive ring has a smaller radius than the previous one. This section describes the CRT that is used in this project: PDS/CRT Heerlen D14-363GY. Figure 2.4a shows an image of said CRT and fig. 2.4b shows a schematic depiction. The cathode is not visible, as it is fixed inside the Wehnelt cylinder (1), just a few millimeters from the exit of the Wehnelt cylinder the electrons pass through the hole in the anode (2), they gain their full kinetic energy over this short distance. The electrons that go through the hole and enter the electrostatic lens, have 2 keV and therefore move at a speed of approximately $0.08c$. The electrostatic lenses are realized using three conducting rings (3), that are set to the same potential but have varying radii: Each consecutive ring has a smaller radius than the previous one.

Between the electrostatic lens and the deflection plates, there is another aperture (4), which is internally connected to the anode and is thereby kept at the same potential. In our Setup, the deflection plates are not simply parallel but are shaped like funnels (5,7), between the two pairs of deflection plates, we have the final aperture (6), this ones potential can be regulated separately (usually it's on the same potential as the anode) Between the electrostatic lens and the deflection plates, there is another aperture (4), which is internally connected to the anode and is thereby kept at the same potential. In our Setup, the deflection plates are not simply parallel but are shaped like funnels (5,7), between the two pairs of deflection plates, we have the final aperture (6). Its potential can be regulated separately (usually it's on the same potential as the anode)

It is connected to the aquadag coating inside the glass envelope and prevents charge up and image distortion. Finally the beam hits the phosphorous-coated screen which fluoresces on electron impact. It is connected to the aquadag coating inside the glass envelope and prevents charge building up, that could lead to image distortions. Finally the beam hits the phosphorous-coated screen, which fluoresces on electron impact.



(a) Image picture of the Heerlen D14-363GY



(b) Schematic of the CRT from [D14363GY123-manual]

Figure 2.4

2.2.1 The Cathode

As already mentioned, we are using a hot cathode, where electrons are excited thermally until some of them acquire enough energy to leave the material. Compared to cold cathodes which work by field emission, this leads to a broader energy distribution. In fields like electron microscopy, where a high resolution is the goal, this is undesirable as it leads to some degree of chromatic aberration in the electron optics; for our purposes, this should not be a problem. On the other hand, hot cathodes normally allow for higher current densities, which is very important to us. The electron current from this kind of emission is described by [Whitaker]: As already mentioned, we are using a hot cathode, where electrons are thermally excited to leave the material. Compared to cold cathodes which work by field emission, this leads to a broader energy distribution. For electron microscopy, where a high resolution is the goal, this is undesirable, as it leads to some degree of chromatic aberration in the electron optics; for our purposes, this should not be a problem. On the other hand, hot cathodes normally allow for higher current densities, which is very important to us. The electron current by thermal emission is described by [Whitaker]:

$$I = A \cdot T^2 \cdot e^{-b/T} \quad (2.3)$$

Where b is proportional to the work function of the material, T is temperature and A is a material-dependent constant. It is clear from this formula, that a low work function and a high melting point are important characteristics for a good cathode material.

The cathode from one of our Heerlen D14-363GY-tubes has been removed and examined with EDX (Energy-dispersive X-ray Spectroscopy). Nickel, barium, and strontium have been found, which suggests that it is a metal oxide cathode with barium-, strontium-, and possibly aluminum-oxide. This type of cathode is very common in low power electron tubes.

The “Power Vacuum Tubes Handbook” [Whitaker] describes a typical oxide cathode as a coating of barium and strontium oxides on a structure made from nickel alloys. Nickel is chosen for its strength and toughness, which it retains even at high temperatures. These cathodes are normally made by coating a case structure with a mixture of barium and strontium carbonates (typically 60 % Ba and 40 % Sr), suspended in a binder material and then baking the structure, causing the carbonates to be reduced to oxides. The “Power Vacuum Tubes Handbook” [Whitaker] describes a typical oxide cathode has a coating of barium and strontium oxides on a structure made from nickel alloys. Nickel is chosen for its strength and toughness, which it retains even at high temperatures. These cathodes are normally made by coating a case structure

¹ with a mixture of barium and strontium carbonates (typically 60 % Ba and 40 % Sr),
² suspended in a binder material and then baking the structure, causing the carbonates
³ to be reduced to oxides.

⁴ These metal oxide cathodes normally operate at 700 °C to 820 °C and are capable of
⁵ average emission densities of 100 mA cm^{-2} to 500 mA cm^{-2} . Still higher peak emissions
⁶ are possible for shorter periods of time; as already mentioned, one of the advantages of
⁷ this type of cathode is its high emission current capability compared to cathodes made
⁸ from other materials. Downsides to this cathode type are its greater susceptibility
⁹ to so-called oxygen poisoning and to ion bombardment. The literature therefore
¹⁰ recommends to avoid prolonged exposure to oxygen. Oxygen poisoning is the process
¹¹ in which oxygen adsorbs onto the cathode and increases its work function, effectively
¹² reducing the ability to emit electrons. Also the material from the oxide cathode
¹³ will evaporate during the tube's lifetime and will travel to other parts of the tube,
¹⁴ adsorbing to electron optics parts and turning them into additional emitters. The
¹⁵ literature (also from [Whitaker]) therefore also advises against exceeding the design
¹⁶ value for the heater voltage, as this reduces the lifetime of the cathode significantly.
¹⁷ (However during the course of our project, we did drive the cathode with higher heater
¹⁸ voltages on various occasions in order to increase the available beam current.) These
¹⁹ metal oxide cathodes normally operate at 700 °C to 820 °C and are capable of average
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²² cathode is its high emission current capability compared to cathodes made from other
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²⁶ adsorbs onto the cathode and increases its work function, effectively reducing the ability
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³¹ reduces the lifetime of the cathode significantly. (However, during the course of our
³² project, we did drive the cathode with higher heater voltages on various occasions in
³³ order to increase the available beam current.)

with what result?

³⁴ 2.2.2 Cathode Layout

³⁵ Figure 2.5 shows how metal oxide cathodes for CRTs typically look; the depiction agrees
³⁶ very well with the layout of our cathode. On the image we see the cathode cylinder,
³⁷ which corresponds to the nickel support structure mentioned above. It is shaped into a

2 Cathodic Ray Tube Basics

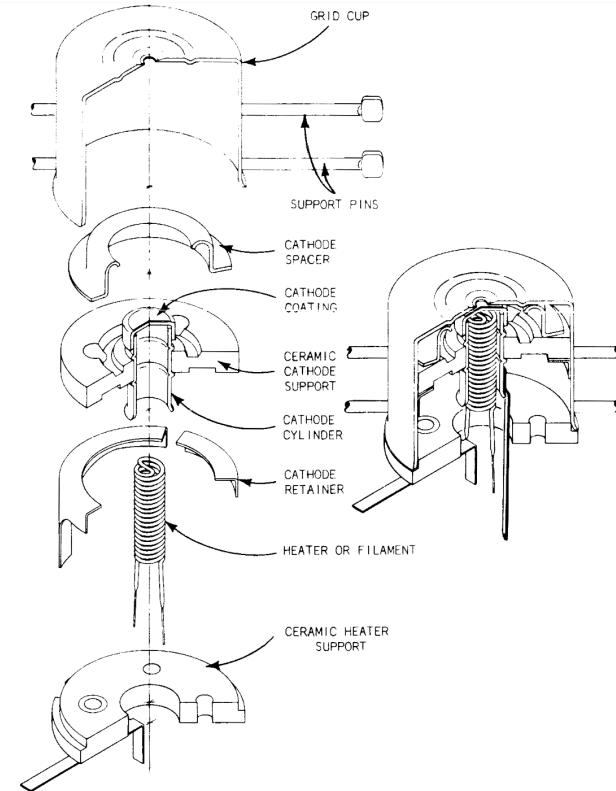


Figure 2.5: Schematic of the layout of a typical CRT-cathode from [deVere69]

cup, i.e. the cylinder is hollow and open on one side, where the heater filament (shaped into a heater coil) is inserted. The oxide disk, from where the electrons are emitted, is baked onto the top of the cathode cylinder. The cathode cylinder is mounted on an isolating support structure and inserted into the Wehnelt cylinder, which is called “grid cup” in the drawing. Figure 2.5 shows how metal oxide cathodes for CRTs typically look. The depiction agrees very well with the layout of our cathode. On the image we see the cathode cylinder, which corresponds to the nickel support structure mentioned above. It is shaped into a cup, in which the heater filament (shaped into a coil) is inserted. The oxide disk, from where the electrons are emitted, is baked onto the top of the cathode cylinder. The cathode cylinder is mounted on an isolating support structure and inserted into the Wehnelt cylinder, which is called “grid cup” in the drawing.

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¹ 3 Cicero Word Generator

² This chapter describes the installation and initial setup of Cicero Word Generator
³ [keshet2013distributed] on a PC running Windows 10 with analog and digital cards from National Instruments (NI). The code is freely available on GitHub
⁴ [akeshet:Github]. This chapter contains only differences, problems, and possible
⁵ solutions encountered when Cicero was installed for the PC ‘Fritz Fantom’ which will
⁶ be used for the QuaK experiment. It is therefore advised to use the technical and user
⁷ manual [akeshet:manual] in conjunction. The titles in this chapter and font style with
⁸ Courier and Boldface was mirrored in order to fit the manual. This chapter describes
⁹ the installation and initial setup of Cicero Word Generator [keshet2013distributed]
¹⁰ on a PC running Windows 10 with analog and digital cards from National Instruments
¹¹ (NI). The code is freely available on GitHub [akeshet:Github]. This chapter contains
¹² only differences, problems, and possible solutions encountered when Cicero was installed
¹³ on the PC ‘Fritz Fantom’, which is used to control the QuaK experiment. It is advised
¹⁴ to use the technical and user manual [akeshet:manual] in conjunction. The titles in
¹⁵ this chapter and font style with Courier and Boldface was mirrored in order to fit
¹⁶ the manual.

¹⁸ 3.1 Installation of National Instruments drivers

¹⁹ Before setting up the Cicero Word Generator, it is necessary to install the newest .NET
²⁰ Framework [microsoft:download.net] from Microsoft. For the first installation of
²¹ NI drivers, NI-DAQmx (version 9.3), NI-VISA (newest version), and NI-4888.2 (newest
²² version) should be downloaded from the National Instruments website [ni:drivers].
²³ When installing the NI drivers it is possible to get an ‘Runtime Error!’. In this case it is
²⁴ necessary to set the Regional format settings of Windows 10 to ‘English (United States)’
²⁵ [ni:runtimerror]. Before setting up the Cicero Word Generator, it is necessary to
²⁶ install the newest .NET Framework [microsoft:download.net] from Microsoft. Then
²⁷ NI drivers, NI-DAQmx (version 9.3), NI-VISA (newest version), and NI-4888.2 (newest
²⁸ version) should be downloaded from the National Instruments website [ni:drivers] and
²⁹ installed. When installing the NI drivers it is possible to get an ‘Runtime Error!’. In
³⁰ this case it is necessary to set the Regional format settings of Windows 10 to ‘English

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(United States)' [ni:runtimerror].1

3.2 Installation of National Instruments Cards2

After installation of the necessary drivers, the physical cards can be inserted into the PCIe slots on the motherboard. On ‘Fritz Fantom’ the digital card (NI PCIe-6537B) was installed in PCIe bus 3 while the analog cards (NI PCIe-6738) were installed in PCIe bus 4 and 5. After installation of the necessary drivers, the physical cards can be inserted in the PCIe slots on the motherboard. On ‘Fritz Fantom’ the digital card (NI PCIe-6537B) was installed on PCIe bus 3 while the analog cards (NI PCIe-6738) were installed on PCIe bus 4 and 5.3
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3.3 Configuring Atticus10

After installation of the NI cards, Atticus should be launched for the first time and closed without changing any settings. After this, the NI-DAQmx drivers should be updated to the newest version. If version 9.3 was not used when launching Atticus in this step, it could result in an error. After this, “Configuring Atticus” on the user manual can be followed. The **Server Name** was set to ‘Fritz_Phantom’. **Dev1** to **Dev3** were set in the same ascending order as the physical installation on the motherboard. After installation of the NI cards, Atticus should be launched for the first time and closed without changing any settings. After this, the NI-DAQmx drivers should be updated to the newest version. If version 9.3 was not used when launching Atticus in this step, it could result in an error. After this, “Configuring Atticus” on the user manual can be followed. The **Server Name** was set to ‘Fritz_Phantom’. **Dev1** to **Dev3** were set in the same ascending order as the physical installation on the motherboard.11
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15 Change server name in lab? Fantom Phantom
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3.3.1 Configure hardware timing / synchronization24

For synchronization, a **Shared Sample Clock** was used with **Dev1** being the master card. The settings are summarized in table 3.1 and table 3.2. **Dev3** follows the same settings as **Dev2** except ‘SampleClockExternalSource’ was set to ‘/Dev3/RTSI7’. The ‘SampleClockRate’ is set to 350 kHz since this is the fastest rate with all 32 analog channels active. It is possible to raise this to 1 MHz by only using 8 channels (1 channel per bank).25
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Table 3.1: Settings for **Dev1**.

Setting	Value
MasterTimebaseSource	
MySampleClockSource	DerivedFromMaster
SampleClockRate	350000
UsingVariabletimebase	False
SoftTriggerLast	True
StartTriggerType	SoftwareTrigger

Table 3.2: Settings for **Dev2**.

Setting	Value
MasterTimebaseSource	
MySampleClockSource	External
SampleClockExternalSource	/Dev2/RTSI7
SampleClockRate	350000
UsingVariabletimebase	False
SoftTriggerLast	False
StartTriggerType	SoftwareTrigger

¹ 3.4 Configuration and Basic Usage of Cicero

² After setting up the Atticus server, Cicero can be configured. In step 3.c. it is necessary
³ to write the full IP address and not ‘localhost’. Once step 6 is finished, Cicero should
⁴ run without any problems. After setting up the Atticus server, Cicero can be configured.
⁵ In step 3.c. it is necessary to write the full IP address and not ‘localhost’. Once step 6
⁶ is finished, Cicero should run without any problems.

what is step

⁷ 3.5 Saving of Settings and Sequences

⁸ The ‘SettingsData’ of the Server Atticus are saved in C:\Users\confetti\Documents
⁹ \Cicero_Atticus\Cicero\SettingsData while the ‘SequenceData’ of Cicero are saved in
¹⁰ C:\Users\confetti\Documents\Cicero_Atticus\Cicero\SequenceData.

3.6 Sequence length limit

The duration of a sequence is limited to $2^{32}/(16 * 32 * 350 \text{ kHz}) = 23.967 \text{ s}$ coming from a 32-bit application, 16 bit per channel, 32 channels in a NI PCIe-6738 card, and 350 kHz clock rate.

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¹ 4 Electron beam setup

² 4.1 Charatarization of a working CRT

³ HAMEG HM507 oscilloscopes [HM507-manual] were used for testing purposes which
⁴ contain a D14-363GY/123[D14363GY123-manual] CRT. Although it only has a
⁵ bandwidth of 0 MHz to 50 MHz, which is not sufficient for the hyperfine splitting
⁶ frequency of 461.7 MHz of ³⁹K, it was used nevertheless because of its simple con-
⁷ struction and availability. The back pin arrangement is shown in fig. 4.1. HAMEG
⁸ HM507 oscilloscopes [HM507-manual] were used for testing purposes which contain
⁹ a D14-363GY/123[D14363GY123-manual] CRT. Although it only has a bandwidth
¹⁰ of 0 MHz to 50 MHz, which is not sufficient to reach the hyperfine splitting frequency
¹¹ of 461.7 MHz for ³⁹K, it was used nevertheless because of its simple construction and
¹² availability. The back pin arrangement is shown in fig. 4.1.

¹³ The voltages and currents of the necessary pins to drive the CRT were measured
¹⁴ using a 2.5 kV probe with an attenuation ratio of ^{1:100 or 100:1} and are summarized in table 4.1. It
¹⁵ was not possible to measure pin g3 directly. Therefore a HVPS (section 4.2) was used
¹⁶ to set a voltage and the beam diameter was observed. The best focus was achieved
¹⁷ with the value written in the table. The voltage offset of x-, and y-plates was not
¹⁸ possible to measure directly, since it varies with time to draw the necessary image on
¹⁹ the phosphor screen. The given values are the mean of the minimum and maximum
²⁰ measured voltage. The deflection coefficient is summarized in table 4.2. The voltages
²¹ and currents of the necessary pins to drive the CRT were measured using a 2.5 kV probe
²² with a voltage divider of 100:1 ^{and are summarized in table 4.1. It was not possible} or was it 1000:
²³ to measure pin g3 directly. Therefore a HVPS (section 4.2) was used to set a voltage
²⁴ and the beam diameter was observed. The best focus was achieved with the value
²⁵ written in the table. The voltage offset of x-, and y-plates was not possible to measure
²⁶ directly, since it varies with time to draw the necessary image on the phosphor screen.
²⁷ The given values are the mean of the minimum and maximum measured voltage. The
²⁸ deflection coefficient is summarized in table 4.2.

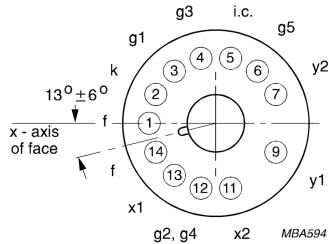


Figure 4.1: Pin arrangement, bottom view from [D14363GY123-manual]

Table 4.1: D14-363GY/123 CRT pin measurements

number	pin	voltage/V	current/ μ A
1	f	-1.99×10^3	86.6×10^3
2	k	-2.00×10^3	-7.6
3	g1	-2.03×10^3	0
4	g3	-1.813×10^3	0
5	i.c.	71.7	0.1
6	g5	64.0	7.2
7	y2	78	-
9	y1	78	-
11	x2	96	-
12	g2, g4	71.0	0
13	x1	96	-
14	f	-1.97×10^3	-86.2×10^3

Table 4.2: D14-363GY/123 deflection coefficient from [D14363GY123-manual]

horizontal	M_x	19 V/cm
vertical	M_y	11.5 V/cm

4.2 High Voltage Power Supply HVPS

To produce high dc voltages to drive the CRT, four HCP 14-6500 power supplies [fug-hcp-manual] were used. They were named ‘HVPS 1’ to ‘HVPS 4’ and can provide up to ± 6.5 kV and 2 mA. To connect the output to the CRT pins, BNC cables were refitted with a save high voltage (SHV) connector on one side while on the other end the BNC connector was kept (fig. 4.2). A 6 kV probe was used to obtain the breakdown voltage, which is around 3 kV caused by the coaxial cable which was not built do sustain high voltages. To produce high dc voltages to drive the CRT, four HCP 14-6500 power supplies [fug-hcp-manual] were used. They were named ‘HVPS 1’ to ‘HVPS 4’ and can provide up to 2 mA at ± 6.5 kV. To connect the output to the CRT pins, BNC cables were refitted with a save high voltage (SHV) connector on one side while on the other end the BNC connector was kept (fig. 4.2). A 6 kV probe was used to obtain the breakdown voltage, which is around 3 kV caused by the coaxial cable which was not built do sustain high voltages.

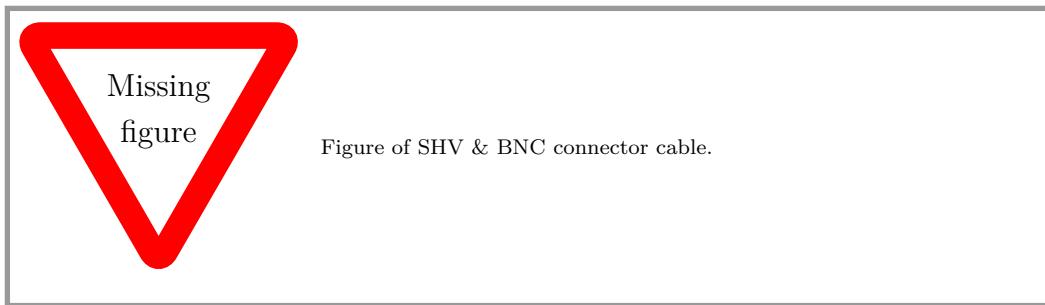


Figure 4.2: Coaxial cable with SHV and BNC connector.

4.2.1 Ripple measurement

Each power supply was measured for its ripple with a set voltage of 2 kV. A 2.5 kV probe (attenuation ratio) was connected to an oscilloscope set to ac coupling with a timescale of 1 ms. To get the electronic noise of the oscilloscope itself, the probe was shorted and the noise measured. A picture of a measurement is shown in fig. 4.3 with the values summarized in table 4.3. As can be seen, the ripple is very close to the noise level and can not really be distinguished. Each power supply was measured for its ripple with a set voltage of 2 kV. A 2.5 kV probe (attenuation ratio) was connected to an oscilloscope set to ac coupling with a timescale of 1 ms. To get the electronic noise of the oscilloscope itself, the probe was shorted and the noise measured. A picture of a measurement is shown in fig. 4.3 with the values summarized in table 4.3. As can be seen, the ripple is very close to the noise level and can not really be distinguished.

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4 Electron beam setup

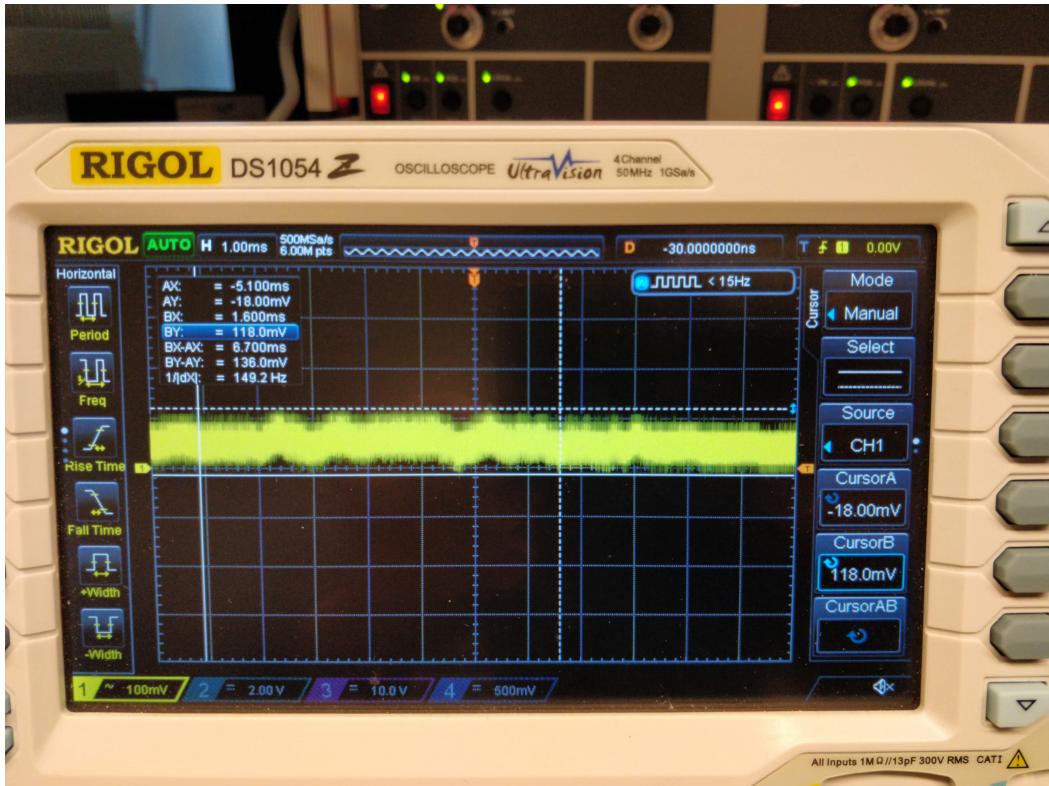


Figure 4.3: Measurement of HVPS ripple.

Table 4.3: HVPS ripple

device	ripple/mV
short	116
HVPS 1	136
HVPS 2	138
HVPS 3	194
HVPS 4	204

¹ 4.3 CRT wiring

- ² A schematic of the supplied power is shown in fig. 4.4. A small ac or dc voltage
³ is necessary to drive the heater filament f. This part of the setup is explained in
⁴ section 4.4.

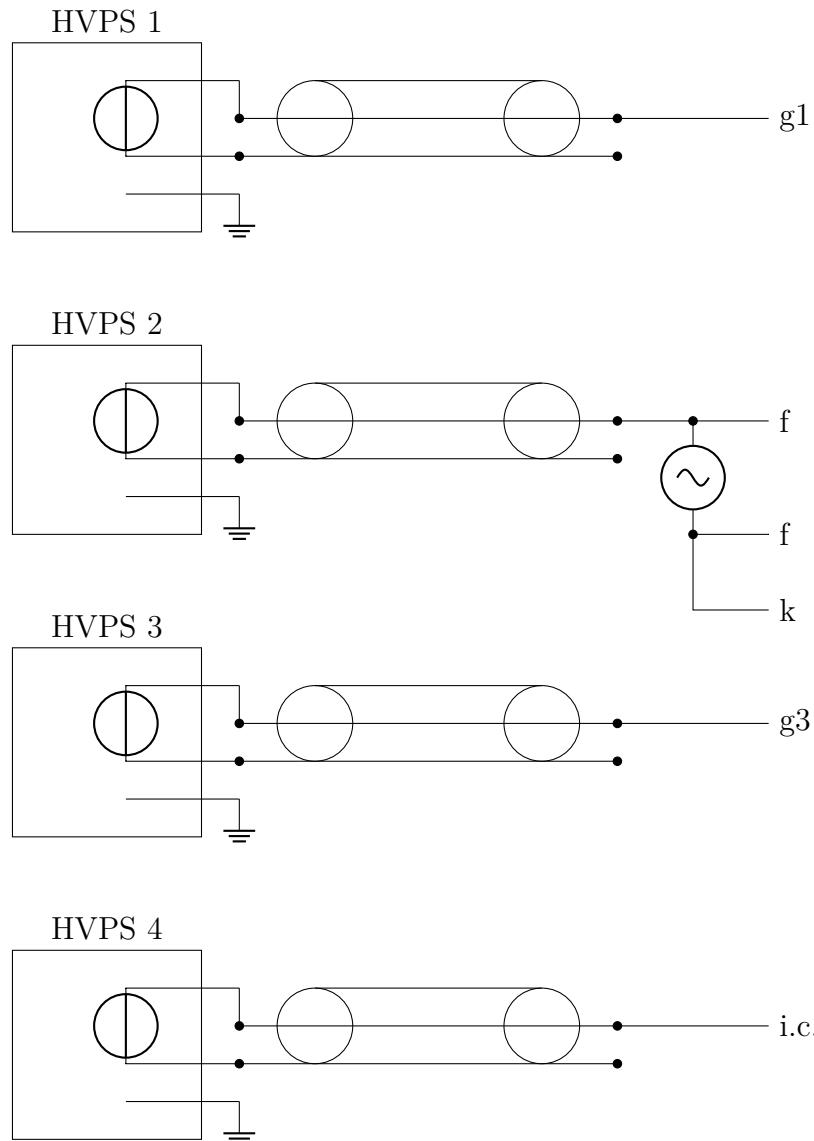


Figure 4.4: Schematics of supplying CRT pins with power.

5

explain what
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4.4 Heater

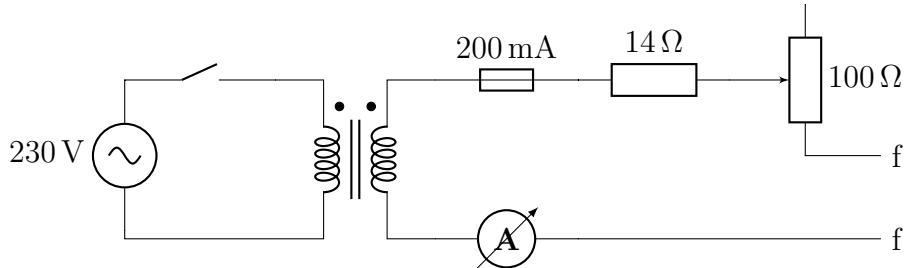


Figure 4.5: Circuit diagram of filament power supply.

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of the final b

The heater provides an adjustable ac voltage, which is used to regulate the temperature of the cathode. In the cold state, the heater filament has a an electrical resistitance of approximately 15Ω , when the filament is hot, this value rises to 90Ω . The normal heater voltage for the D14-363GY/123 during operation is 6.0 V to 6.6 V according to [D14363GY123-manual]. Our ac-power supply (figure 4.5 shows its circuit diagram) consists of an isolation transformer (from grid voltage to 12 V), its primary and secondary circuits are isolated up to 4 kV [DS44231-DataSheet]. The power supply has two banana plug sockets to connect to the heater filament. It is connected to the transformer in series with a 100Ω potentiometer. Using the full resistance, there is a voltage of approximately 5.7 V applied to the heater filament, by lowering the resistance this value can goes up to nearly the full voltage of the transformer. The current running through the filament is measured with an integrated amperemeter [ACA-20PC-manual] that measures currents up to two 2 A with mA accuracy. The current running through the filament is measured with an integrated ampere meter [ACA-20PC-manual], that measures currents up to two 2 A with mA accuracy.

At the beginning of operation it is recommendable to set the maximum resistance and slowly increase the current to the desired value once the filament is heated up. As the resistance of the cold filament is significantly lower, high onset currents could otherwise damage it.

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¹ 5 CRT handling

² 5.1 Opening CRTs

³ In order to hit the ^{39}K cloud with an electron beam, it is necessary to cut open the
⁴ CRT. This section explains the different methods which were tried and which resulted
⁵ in clean and easy cuts. All slices were made in a glove box filled with nitrogen gas
⁶ (fig. 5.1) to avoid oxygen poisoning of the cathode. In order to have a free electron
⁷ beam in the experimental setup, to hit a cold ^{39}K , it is necessary to cut open the
⁸ CRT. This section explains the different methods which were tried and which resulted
⁹ in clean and easy cuts. All slices were made in a glove box filled with nitrogen gas
¹⁰ (fig. 5.1) to avoid oxygen poisoning of the cathode.

reduce

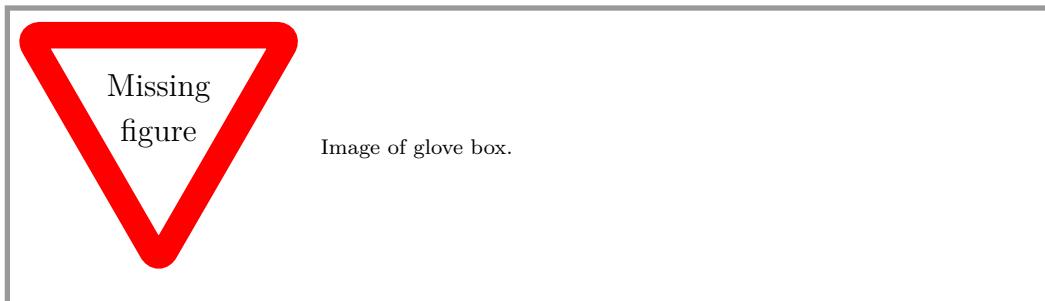


Figure 5.1: Glovebox filled with nitrogen gas to open CRTs.

¹¹ 5.1.1 Rotary tool

¹² First, a small hole was drilled in the center of the CRT pins to pressurize the CRT
¹³ with nitrogen. Then a diamond wheel attached to a rotary tool was used to cut the
¹⁴ glass. This method was tried twice, but did not work well, as the method produced a
¹⁵ lot of glass dust, which adhered to the electron optics. Another obstacle is the plastic
¹⁶ box, since it is not fully transparent and therefore made more difficult to see inside.

5.1.2 Wire cutting

Higher success was achieved by cutting the glass with a heated wire. Two wires were put through the glove box, each ending in a ring terminal. A small height adjustable stage was built out of optical table parts (fig. 5.2) in which the CRT was put vertically and looped by an 0.25 mm steel wire (Fe 70/Cr 25/Al 5). It is important to keep a small gap in the loop to avoid an electrical short. Therefore two notches were made in which the wire was fixed. Higher success was achieved by cutting the glass with a heated wire. Two wires were put through the glove box, each ending in a ring terminal. A small height adjustable stage was built out of optic element mounts (fig. 5.2) in which the CRT was put vertically and looped by an 0.25 mm steel wire (Fe 70/Cr 25/Al 5). It is important to keep a small gap in the loop to avoid an electrical short. Therefore two notches were made in which the wire was fixed.

The assembly was put inside the glove box which was subsequently filled with nitrogen. A current of approximately 2 A to 2.5 A was used to heat the thin wire which resulted in a breaking point inside the CRT glass. This method does not require a CRT pressurization before the cut. In order to not destroy a device by mistake, this procedure can first be tested on drinking glasses. The assembly was put inside the glove box, which was subsequently filled with nitrogen. A current of approximately 2 A to 2.5 A was used to heat the thin wire which resulted in a breaking point inside the CRT glass. This method does not require a CRT pressurization before the cut. In order to not destroy a device by mistake, this procedure was first extensively tested on drinking glasses.

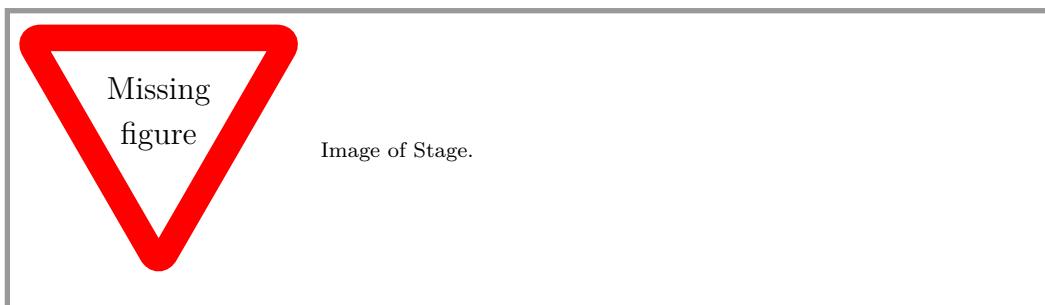


Figure 5.2: Stage to cut CRT with wire.

5.2 Oxygen poisoning

As mentioned in chapter 2 it is paramount to avoid contact of the cathode with oxygen. Therefore tests with a broken CRT were made to test on how well it can be isolated

5 CRT handling

¹ from air.

² The first experiment consisted of filling a drinking glass put upside-down with helium
³ and putting a lighter after a set amount of time. If the fire goes off, it means that
⁴ oxygen did not get inside. This was tested successfully from 0.5 min to 10 min.

⁵ Next, plastic wrap was put on top of the glass filled with nitrogen by a rubber band.
⁶ The glass was put with the open side up from 3 min to 10 min after which it was turned
⁷ upside down and the foil was removed. A lighter was put inside and the flame went
⁸ out again.

⁹ To improve the sensitivity, a He leak tester was used. For the first two tests, one
¹⁰ plastic foil and one rubber band were used, for the third test three foils and two rubber
¹¹ bands, and for the last test an aluminum foil was hot glued on the CRT to seal it. The
¹² measurement locations are shown in fig. 5.3. As shown in table 5.1 using rubber band
¹³ and clear foil results in the highest leakage while the glue seals much better (glue avg).
¹⁴ But care needs to be taken in order ensure that the whole CRT is sealed since even a
¹⁵ small leak can result in a rate around an order of magnitude above the background
¹⁶ (glue max). To improve the sensitivity , a He leak tester was used. For the first two precision
¹⁷ tests, one plastic foil and one rubber band were used, for the third test three foils and
¹⁸ two rubber bands, and for the last test an aluminum foil was hot glued on the CRT to
¹⁹ seal it. The measurement locations are shown in fig. 5.3. As shown in table 5.1 using
²⁰ rubber band and clear foil results in the highest leakage while the glue seals much
²¹ better (glue avg) . But care needs to be taken in order ensure that the whole CRT is what does avg mean
²² sealed since even a small leak can result in a rate around an order of magnitude above
²³ the background, as it can be seen in the measurement (glue max).

Table 5.1: He leak test.

location	leak rate/(10 ⁻⁵ mbar l/s)
1 plastic foil, 1 rubber band	
background	8
plastic foil	20
He gas cylinder	200
1 plastic foil, 1 rubber band	
background	7
plastic foil	20
rubber band	40
3 foils, 2 rubber bands	
background	20
plastic foil	30
rubber band	70
1 aluminum foil, hot glue	
background	6
glue avg	7
glue max	60
aluminum foil	8

5 CRT handling



(a) plastic foil



(b) rubber band



(c) glue



(d) aluminum

Figure 5.3: Measurement locations of He leakage.

6 Vacuum test chamber

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In order to be able to fit the CRT screen, CF160 flanges were chosen for the test chamber. At one point during testing, major changes were made which will be explained in section 6.2.

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explain more in detail what is the purpose of the chamber the two iterations are not really important built this chamber rather ab the function operation of chamber over time due to gassing the pressure improvement

6.1 First iteration

A 3D render of the chamber is shown in (fig. 6.1). Without a CRT installed, it was possible to reach a pressure of 6.8×10^{-7} mbar, while with one the lowest was 2.0×10^{-6} mbar. A 3D render of the chamber is shown in (fig. 6.1). Without a CRT installed, it was possible to reach a pressure of 6.8×10^{-7} mbar, while with one the lowest was 2.0×10^{-6} mbar.

6.1.1 Parts

6.1.2 Parts

The center piece consists of a 6-way cross with view ports at the front and bottom. A valve was installed at the back in order to flood the chamber with nitrogen when installing a new CRT to avoid oxygen poisoning. On the right side, a HiCube 300 Eco turbo pump was installed and on the left side a wobble stick was attached with a wire. A nipple fitting was installed at the top with a 5 port cluster flange, each being of type CF63. The center piece consists of a 6-way cross with view ports at the front and bottom. A valve was installed at the back in order to flood the chamber with nitrogen , when installing a new CRT to avoid oxygen poisoning . On the right side, a HiCube 80 Eco turbo pump was installed and on the left side a wobble stick was attached with a wire . A straight CF100 pipe was installed at the top with a 5 port cluster flange, each being of type CF40.

In the middle port, a VSH vacuum transducer was installed to measure pressure. This needs a 24 V dc power supply. On the left, a 19 pin connector was installed to supply the necessary voltages to the CRT. Two flanges were equipped with four

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length=27cm

6 Vacuum test chamber

¹ BNC feedthroughs each. One of them was used to connect do the x-, and y-plates,
² while the other connected to the wobble stick and aluminum foil at the CRT screen.
³ Further explanation will be given in chapter 8. The last port was capped off by a blank
⁴ flange. In the middle port, a VSH pressure gauge was installed. On the left, a 19 pin
⁵ connector was installed to supply the necessary voltages to the CRT. Two flanges
⁶ were equipped with four BNC feedthroughs each. One of them was used to connect do
⁷ the x-, and y-plates, while the other connected to the wobble stick and aluminum foil
⁸ at the CRT screen. Further explanation will be given in chapter 8. The last port was
⁹ capped off by a blank flange.

¹⁰ For the inside wires, stranded copper cables were used. The chamber was sealed by
¹¹ rubber gaskets. For the inside wires, standard copper cables were used. The chamber
¹² was sealed by rubber gaskets.

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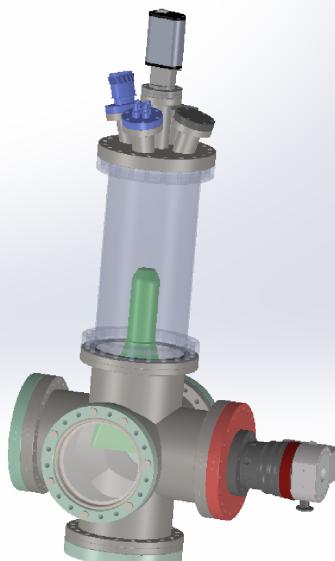


Figure 6.1: 3D rendering of test chamber.

¹³ 6.1.3 CRT mounting mechanism

¹⁴ Two M8 rods of length were drilled into the cluster flange. On each, a L-piece was
¹⁵ installed between two nuts and they were connected by a hose clamp. Two of these
¹⁶ were used to secure the CRT inside the nipple facing the cross (fig. 6.2). Two M8 rods

rod length?

of length were drilled into the cluster flange. On each, a L shaped aluminum piece was installed between two nuts. These were then connected by a hose clamp, which was used to secure the CRT inside below the cluster flange (fig. 6.2).

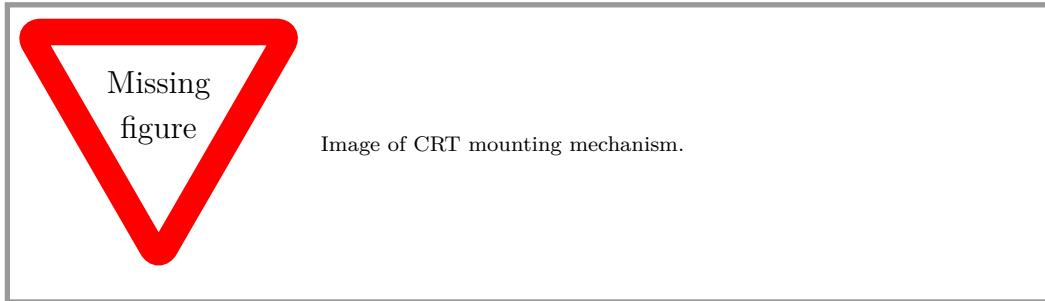


Image of CRT mounting mechanism.

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Figure 6.2: Image of CRT mounting mechanism.

6.1.4 Leak test

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6.1.5 Leak test

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Before inserting a CRT, a leak test was performed. First, the chamber was set to a pressure of 10^{-5} mbar after which the pump was turned off. The pressure was measured once a minute for a duration 3 h. This is shown in fig. 6.3. Before inserting a CRT, a leak test was performed. First, the chamber was set to a pressure of 10^{-5} mbar after which the pump was turned off. The pressure was measured once a minute for a duration 3 h. This is shown in fig. 6.3.

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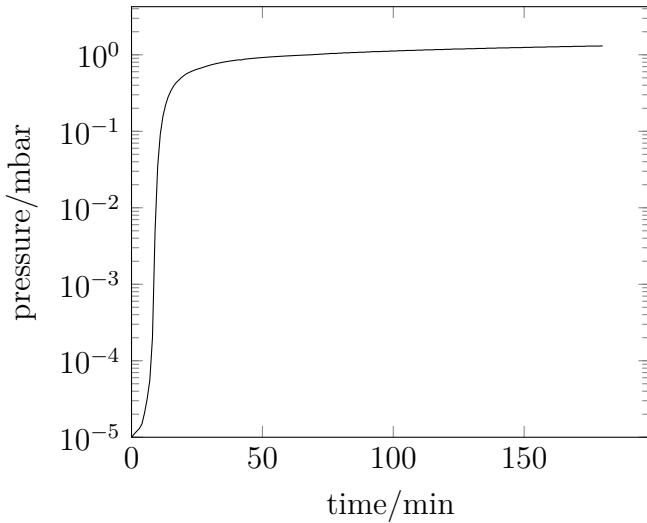


Figure 6.3: Leak rate of test chamber after turning off pump.

¹ 6.2 Second iteration

² At one point during experimentation, major changes were made to the chamber. Thanks
³ to these, it was possible to reach a pressure of 1.2×10^{-7} mbar.

⁴ 6.2.1 Changes

⁵ First, every rubber gasket was changed to a copper one for a better seal, except at the
⁶ cluster flange, since that spot will be opened and closed the most often. Each copper
⁷ stranded cable inside was switched to a coaxial one and the mantle was connected to
⁸ the chamber wall, which was set to ground. A Faraday cup was installed below the
⁹ wobble stick, to accurately measure the beam current (further details in section 8.2).
¹⁰ The aluminum foil was extended to cover all four sides of the screen. First, every rubber
¹¹ gasket was exchanged to a copper one for a better seal, except at the cluster flange,
¹² since that spot will be opened and closed the most often. Each copper stranded cable
¹³ inside was switched to a coaxial one and the mantle was connected to the chamber
¹⁴ wall, which was set to ground. A Faraday cup was installed below the wobble stick, to
¹⁵ accurately measure the beam current (further details in section 8.2). The aluminum
¹⁶ foil was extended to cover all four sides of the screen.

6.2.2 Fastening

When attaching flanges, it is important to start with a low torque and to fasten opposite screws to prevent too much force on one side of the gasket. For M6 screws, the torque was incrementally set to 6 N m, 10 N m, 15 N m and 20 N m and for M8 screws 8 N m, 16 N m and 25 N m. After finishing every opposite screw pair at a set torque, the procedure was repeated twice before going to a higher torque. This was done in order guarantee a tight and even seal.

¹ 7 Deflection Electronics

² 7.1 Demands on the setup

³ For the QuaK experiment it is paramount to be able to deflect the beam precisely
⁴ and with the right frequency. For the QuaK experiment it is paramount to be able
⁵ to deflect the beam precisely at the right frequency. As previously mentioned, our
⁶ deflection system simply consists of two pairs of parallel plates between which a voltage
⁷ is applied. Controlling this voltage allows us to control the deflection of the beam.
⁸ Various aspects are important here (illustrated in fig. 7.1):

of a sufficient current

with a sufficient small enough bandwidth

Optional: insert Foto of CRT's flection plates - fig:DeflectionSe

⁹ **Offset:** Although the deflection of the beam is controlled by the voltage between the
¹⁰ plates, it is necessary to be able to set their mean potential as well. During
¹¹ normal operation this offset voltage is at 96 V for the x-direction and at 78 V for
¹² the y-direction.

what happens when there is no bias voltage what is the purpose of it

¹³ **Offset:** Although the deflection of the beam is controlled by the voltage between the
¹⁴ plates, it is necessary to be able to set their mean potential as well. During
¹⁵ normal operation this offset voltage is at 96 V for the x-direction and at 78 V for
¹⁶ the y-direction.

¹⁷ **Amplitude:** The deflection coefficients in the x and y planes are 19 V cm^{-1} and
¹⁸ 11.5 V cm^{-1} respectively (see [D14363GY123-manual]). We therefore need
¹⁹ to be able to supply approximately 70 V.

to achieve w

²⁰ **Amplitude:** The deflection coefficients in the x and y planes are 19 V cm^{-1} and
²¹ 11.5 V cm^{-1} respectively (see [D14363GY123-manual]). We therefore need
²² to be able to supply approximately 70 V.

²³ **Frequency:** The final goal is to be able to deflect the beam at the hyperfine splitting
²⁴ frequency of ${}^{39}\text{K}$, which is 461.7 MHz. This is likely to prove impossible with this
²⁵ CRT-model, observations at the highest frequency we have tried so far will be
²⁶ discussed in section section 8.3.

²⁷ **Waveform:** Ultimately we want the cold atoms to experience a field that oscillates like
²⁸ a sine wave. As a first try it is therefore reasonable to apply a sinusoidal voltage.

Lissajous curves: Having the ability to control the deflection in both the x- and the y- axis, allows us to have our beam draw out Lissajous Curves (fig. 7.2). By applying sine waves of equal frequency to both pairs of deflection plates and by being able to control the phase between them we can have the beam oscillate on a straight line or a circle. This allows us to generate either a linearly or circularly polarized field.

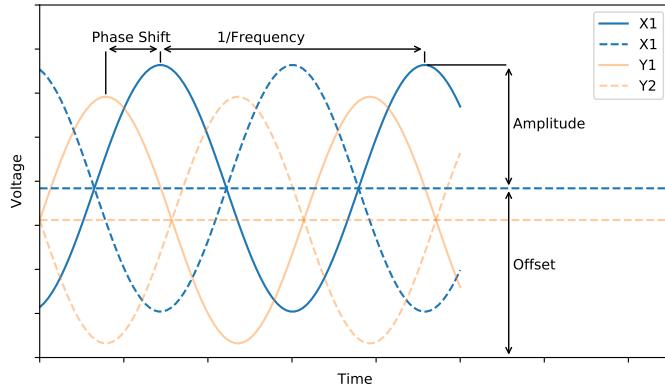


Figure 7.1

$$\phi = 0 \quad \phi = \pi/4 \quad \phi = \pi/2 \quad \phi = 3\pi/4 \quad \phi = \pi$$

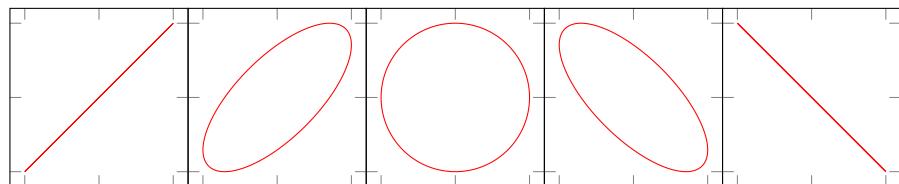


Figure 7.2: Lissajous Curves

7.2 Implementation

A first setup with which we can try to obtain the desired voltages is depicted in fig. 7.3. On the very left we have a signal generator that is capable of producing the right frequency (461.7 MHz) this signal is then split up into an x-, and a y-branch. One of the two branches is connected to a phase shifter, which is able to delay the input signal by up to 200°, allowing us to set any desired phase shift between x-, and y-deflection and to correct for inadvertent delays from the other electronics. Both the

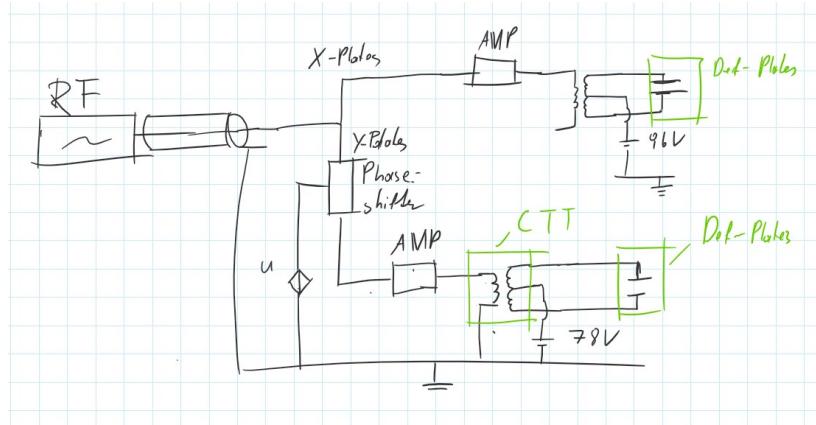


Figure 7.3: Deflection circuit

1 x-, and y-signal are then amplified using (amplifier) . In the final step, a center tapped
 2 transformer allows us to produce voltages for the plates X1 and X2 (or Y1 and Y2
 3 respectively) with a phase shift of exactly 180° between them. By setting the center
 4 tap to the desired offset potential, we should get the voltage curves described above.
 5 To understand this setup in more detail, it is useful to examine its most important
 6 parts more closely:

Find out which amplifier

7 **Amplifier:** Up to now we have used the XXX and the YYY amplifier, they amplify
 8 the signal by a fixed gain of (How much?) , inputs and outputs can simply be
 9 connected via BNC cables, the amplifier is powered by a linear power supply
 10 with a DC voltage of 24 V via two banana plugs in the front. Since we want to
 11 control the Lissajous curves shapes (as the deflection coefficients for the x- and
 12 y- plates differ), it is desirable to be able to adjust the amplifier gain in future
 13 versions of the setup.

which model?

which model?

Check amplifier specifications

14 **Center Tapped Transformer:** The center tapped transformer we use is the Mini-
 15 Circuits TC8-1G2+ ([TC8-1G2]), a transformer for frequencies between 2 MHz
 16 to 500 MHz, with an impedance ratio of 8. Figure 7.6 shows how the center
 17 tapped transformer is implemented. The in- and outputs, as well as the bias
 18 voltage can be connected via BNC cables. As usual, the shields of all these cables
 19 are connected to ground, furthermore they are connected to each other and to
 20 the housing. As a safety feature, both outputs X1 and X2 are directly connected
 21 to the bias through an arrangement of diodes: Two connections, each with a
 22 normal diode and a Zener diode facing in opposite directions. The breakthrough
 23 voltage of the Zener diode is 200 V, during normal operation the voltage on it
 24 stays below this value and none of the connections let any current through as
 25 one of the two diodes is always blocking it. However if one of the plates in the

Optional: Go to lab and measure their performance with an Oszi.

CRT accidentally comes in contact with high voltage, the connection with the appropriately oriented Zener diode opens up, preventing a voltage spike on the center tapped transformer and thereby protecting the electronics connected to its primary circuit. At the point of writing there are still some problems with the behavior of the center tapped transformer, the capacitance of the diodes introduces an undesired phase shift between the two signals. Figure 7.5a shows the circuit's behavior at 465 MHz without its diodes, here the signals are shifted by $120 \text{ ps} \doteq 20^\circ = 0.35 \text{ rad}$. Additionally, applying a bias voltage leads to differing amplitudes, as can be seen in fig. 7.5b.

Phase Shifter: To control the phase shift between the x- and y-deflection plates, we use a Mini-Circuits [JSPHS-661] phase shifter. This part was put in a housing ([Hammond1455D601RD]) on a separate PCB and can be connected via BNC cables. Figure 7.4a shows how the phase shifter is connected and fig. 7.4b shows the corresponding PCB layout. Note that again the shields of the BNC cables are connected among each other and to the housing. The JSPHS-661+ is designed for frequencies in the range 400 MHz to 600 MHz. By applying a DC voltage of 0 V to 12 V to the bias connector, it is possible to introduce a phase shift of up to 200° to the signal.

(figure)
(Performance)

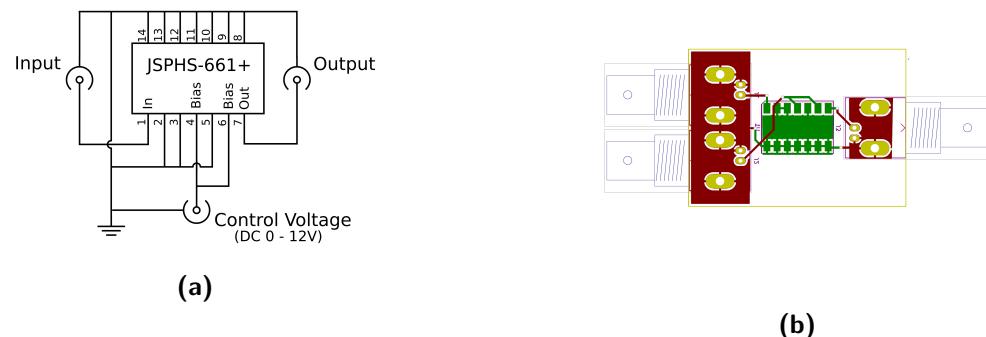


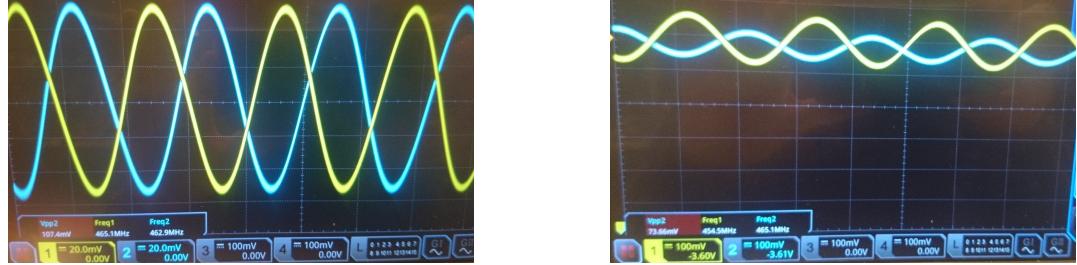
Figure 7.4

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19 Insert fotos of finished circuits in housings
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Optional: Go to the Lab, set the whole thing look at its performance on the

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tion is missin



(a) Signal of center tapped transformer without diodes, unbiased at 465 MHz

(b) Signal of center tapped transformer without diodes, biased at 465 MHz

Figure 7.5

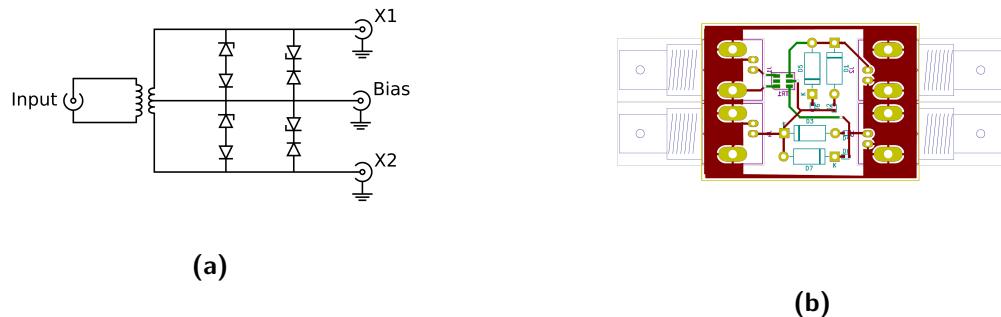


Figure 7.6

8 Beam Characterization

8.1 Aluminum foil

In fig. 8.1 the inside of the 6-way cross of the first iteration is shown. On one side of the phosphor screen, aluminum foil was attached to simulate the aquadag coating inside a CRT. The beam was deflected on the aluminum foil and the BNC output was connected to ground through an ammeter to measure the beam current. As shown in fig. 8.2 there is close to no difference in the filament voltage (and therefore heating power) between an opened and sealed CRT while the beam current on the aluminum foil varies widely. One possible reason could be that electrons scatter around and not all choose the wire path to ground. Therefore a Faraday cup (see section 8.2) was used in the second iteration. In fig. 8.1 the inside of the 6-way cross of the first iteration is shown. On one side of the phosphor screen, aluminum foil was attached to simulate the aquadag coating inside the cut CRT. The beam was deflected on the aluminum foil and the BNC output was connected to ground through an ammeter to measure the beam current. As shown in fig. 8.2 there is close to no difference in the filament voltage (and therefore heating power) between an opened and sealed CRT while the beam current on the aluminum foil varies widely. One possible reason could be that electrons scatter . Therefore, a Faraday cup (see section 8.2) was used in the second iteration.

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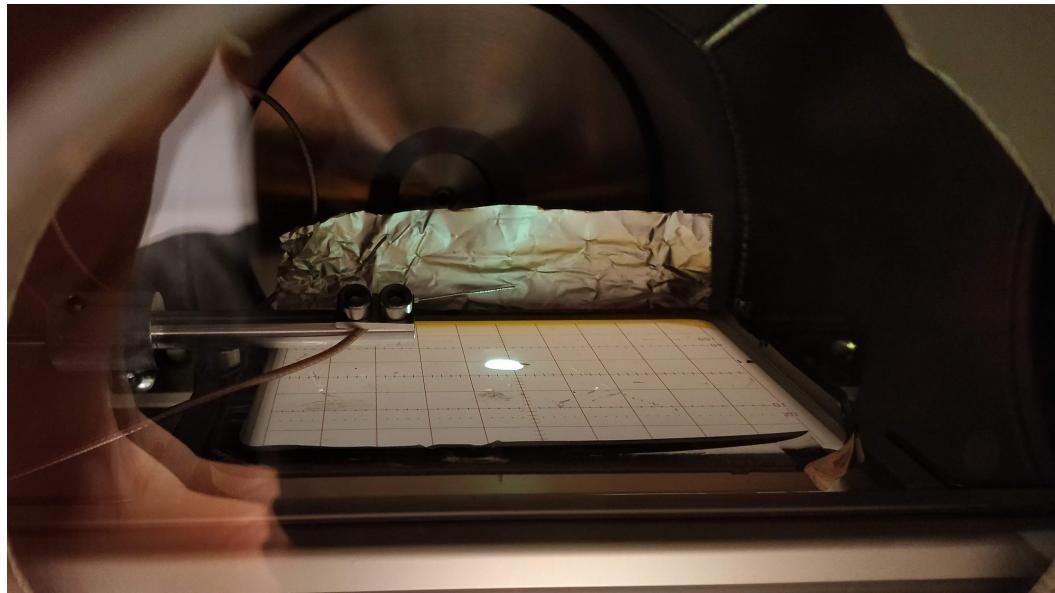


Figure 8.1: Front view of vacuum chamber (first iteration).

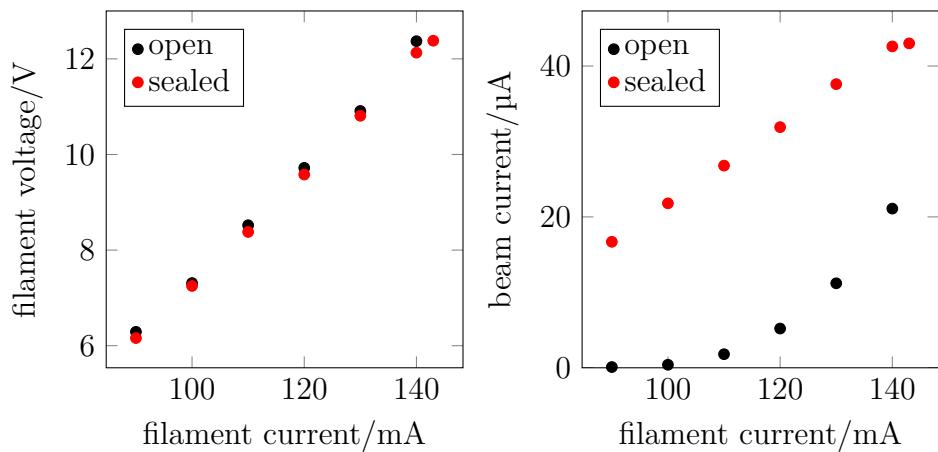


Figure 8.2: Difference in filament voltage and beam current between an open and sealed CRT.

8.2 Faraday cup

In order to accurately measure the beam current, a Faraday cup was built. A schematic is shown in fig. 8.3. A copper tube was cut at an 45° angle on one side and a Cu-sheet was soldered at the top and bottom. A small hole of around 5 mm was drilled at the top and a coaxial cable was attached on the mantle which connects to a BNC feedthrough at the top of the chamber. The small opening and bent floor were made in order to reduce backscattering as indicated by blue arrows. At the top surface a phosphor coating was applied in order to make the beam visible which made it easier to guide it into the opening hole. In order to accurately measure the full beam current, a Faraday cup was built. A schematic is shown in fig. 8.3. A copper tube was cut at an 45° angle on one side and a Cu-sheet was soldered at the top and bottom. A small hole of around 5 mm was drilled at the top and a coaxial cable was attached on the mantle which connects to a BNC feed through at the top of the chamber. The small opening and angled floor were added, in order to reduce electron loss through back scattering, as indicated by blue arrows in fig. 8.3. At the top surface a phosphor coating was applied, in order to make the beam visible. This made it easier to guide it into the opening hole.

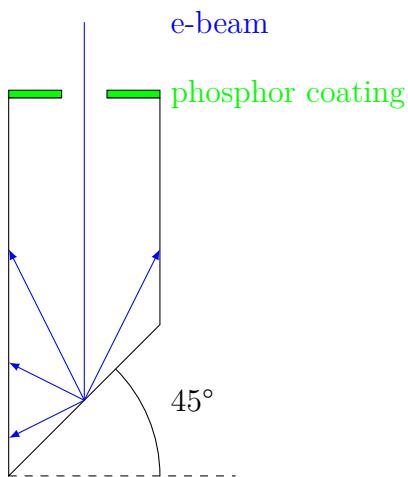


Figure 8.3: Schematics of Faraday cup.

With this improved setup, the beam current was measured again. A summary is shown in fig. 8.4. It can be seen that a current of over $300 \mu\text{A}$ was achieved, which is more than the necessary amount for the experiment. A problem is the fact, that the current is not stable. A measurement on the next day under the same settings resulted in a current between $50 \mu\text{A}$ to $120 \mu\text{A}$. With this improved setup, the beam current was measured again (fig. 8.4). It can be seen, that a current of over $300 \mu\text{A}$ was achieved, which is more than the necessary amount for the experiment. However, through this

¹ measurement it became evident, that the current is not stable. A measurement on the
² next day under the same settings resulted in a current between 50 μA to 120 μA .

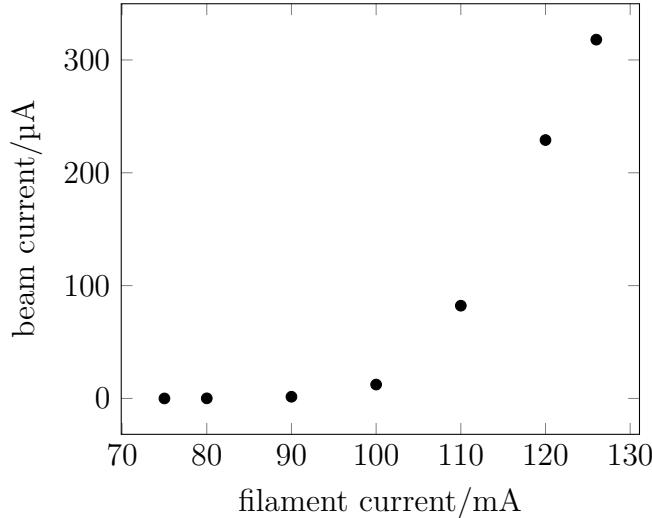


Figure 8.4: Beam current dependence on heater current.

³ 8.3 Deflection frequency

⁴ This section describes a few observations that were made when letting the electron
⁵ beam interact with a short piece of wire, that is mounted to the wobble stick. Originally,
⁶ we hoped to be able to measure the beam waist, using the knives edge method, i.e.
⁷ observing the current transported by the beam, while slowly moving a razor blade into
⁸ the beam path. However the beam is bent, when it passes closely to a conductive part.
⁹ Whenever we moved our wire close to the beam, the visible spot on the Phosphorous
¹⁰ screen below was distorted. This will probably complicate the measurement of the
¹¹ beam waist in the future. This section describes a few observations, that were made
¹² when letting the electron beam interact with a short piece of wire, that is mounted to
¹³ the wobble stick. Originally, we hoped to be able to measure the beam waist, using
¹⁴ the knife edge method, i.e. observing the current transported by the beam, while
¹⁵ slowly moving a razor blade through the beam path. However the beam is bent, when
¹⁶ it passes closely to a conductive part. Whenever, we moved our wire close to the
¹⁷ beam, the visible spot on the Phosphorous screen below was distorted. This will
¹⁸ probably complicate the measurement of the beam waist in the future. When the
¹⁹ wire is connected to an oscilloscope, one can see a sharp increase in voltage, when it
²⁰ is moved into the beam. This can be used to see whether our deflection plates work
²¹ properly and to test how fast we are able to deflect the beam. If the beam oscillates

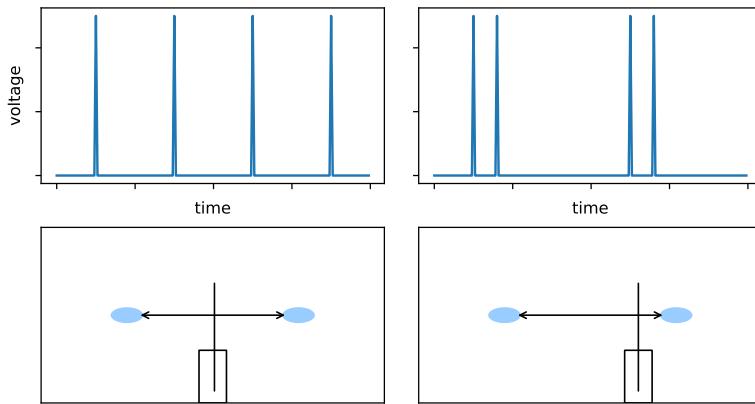


Figure 8.5

back and forth on a straight line and crosses the wire on the midway point, we should see a spike in voltage on the wire, which repeats with twice the frequency of the beam. If the wire is not on the midway point, the periods between consecutive spikes should sum up to the period of the beam's oscillation (see fig. 8.5). At low frequencies we have indeed observed this behavior. As the frequency is increased, the magnitude of the signal decreases. This is easily explained by the fact that the remain time close to the wire is inversely proportional to the frequency and the amplitude of beams deflection. It was possible to see the spikes up to a frequency of 100 kHz, before they where obscured by noise and some other periodical, but so far unexplained artifacts. At high deflection frequencies, the wire may also pick up some signal form the capacitive charging and discharging of the deflection plates and the corresponding oscillating electromagnetic field. In order to be able to see what happens at higher frequencies, a higher beam current and a smaller deflection amplitude would be beneficial, however the most important factor in order to understand what is happening is better focus and a better beam shape. In order to be able to see what happens at higher frequencies, a higher beam current and a smaller deflection amplitude would be beneficial. However, the most important factor in order to understand what is happening, is a better focus and a better beam shape.

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¹ 9 Next Steps

² To conclude this report, we will point out some of the next steps that need to be taken
³ in order to advance the electron beam setup. To conclude this report, we will point
⁴ out some of the next steps, that need to be taken in order to advance the electron
⁵ beam setup.

⁶ **Beam current stability:** The most important challenge at this moment is the ability
⁷ produce a reproducible, stable, and sufficiently strong beam. In order to achieve
⁸ this, more research on cathodes and their susceptibility to oxygen poisoning needs
⁹ to be conducted. It may also prove useful to add another high voltage power
¹⁰ supply to the setup in order to tune the filament potential independently from
¹¹ the Wehnelt cylinder.

¹² **Spot size characterisation:** As previously mentioned, our original attempt was, to
¹³ probe the electron beam's profile using a thin piece of wire on the wobble stick.
¹⁴ However, we have observed that the beam got warped when passing close to
¹⁵ conductive materials, therefore a different approach is needed.

¹⁶ **Heating mechanism:** As high currents will degrade the filament and cathode, it is
¹⁷ desirable to be able to tune the heater current down to 0 mA continuously. Such
¹⁸ a power supply needs to support a bias voltage of around -2 kV.

¹⁹ **Lissajous Curves:** Regarding the deflection electronics, the first issue that needs to
²⁰ be addressed is the fact that it is not possible to produce a clean sine wave when
²¹ a bias voltage is applied to the center tapped transformer. Furthermore, it is
²² recommended to implement the over voltage protection described previously with
²³ very low capacitance diodes.

²⁴ **Beam current stability:** The most important challenge at this moment is the ability to
²⁵ generate a reproducible, stable, and sufficiently strong beam. In order to achieve
²⁶ this, more research on cathodes and their susceptibility to oxygen poisoning needs
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addressed, is the fact that it is not possible to produce a clean sine wave, when
a bias voltage is applied to the center tapped transformer. Furthermore, it is
recommended to implement the over voltage protection described previously with
very low capacitance diodes. In the future, the setup should be able to produce
Lissajous curves at the ^{39}K hyperfine transition frequency of 461.7 MHz.

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shortly referred
to the existing
one we built
how to change

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12 Check whether
have explained
benchmarks for
beam (waist, c
urrent, frequency

¹ Todo list

2	■ set date to English	A
3	■ also potassium 41, we might use this instead due to the smaller frequency	1
4	■ something is broken	1
5	■ use \person{}	1
6	■ this section is sometimes confusing and already deals with out CRT	2
7	■ you can probably explain it in your own words better	2
8	■ let e- come form cathode and not point source in mid air, cathode could be a bit smaller	2
10	■ explain why it has to be a sharp tip already here since it is shown in the picture	2
11	■ this is a strong statement I guess there are limitations to that, maybe a reference would be help full here	4
13	■ können die Maße stimmen?	5
14	■ maybe expplain here what this is	6
15	Figure: Image of CRT	7
16	■ mention why it is important	8
17	■ in our ONEnote are some SEM pictures of the cathode	8
18	■ with what result?	9
19	■ I am not sure what you mean whit this last sentence.	11
20	■ namechange?	12
21	■ what is step 6?	13
22	■ shouldn't the last two subsection be subsubsections?	14
23	■ http://www.tobiastiecke.nl/archive/PotassiumProperties.pdf	15
24	■ http://www.tobiastiecke.nl/archive/PotassiumProperties.pdf	15
25	■ 1:100 or 100:1	15

9 Next Steps

■ or was it 1000:1	15	1
■ somewhere 2.5-4, find exact value	17	2
■ somewhere 2.5-4, find exact value	17	3
Figure: Figure of SHV & BNC connector cable.	17	4
■ 100:1 or 1:100	17	5
■ I think it was 1000:1	17	6
■ explain what i.c. is	19	7
■ check if really 14Ω or if it event exists	20	8
■ also add picture of the final box	20	9
■ reduce	21	10
Figure: Image of glove box.	21	11
Figure: Image of Stage.	22	12
■ precision	23	13
■ what does avg mean	23	14
■ explain more in detail what is the purpose of the chamber, the two iterations are not really important built this chapter rather about the function and operation of the chamber over time due to outgassing the pressure improved)	15	15
■ explain more in detail what is the purpose of the chamber, the two iterations are not really important built this chapter rather about the function and operation of the chamber over time due to outgassing the pressure improved)	16	16
■ explain more in detail what is the purpose of the chamber, the two iterations are not really important built this chapter rather about the function and operation of the chamber over time due to outgassing the pressure improved)	17	17
■ not sure what you mean here	26	18
■ unmeaning title	26	19
■ pure nitrogen name?	26	20
■ length	26	21
■ pure nitrogen name?	26	22
■ Alphagaz TM 1 N_2 purity $\geq 99.999\%$	26	23
■ water vapor getting into the chamber	26	24
■ explain in connection of the rendering; this makes it easier, if necessary you can get more renderings	25	25
■ explain in connection of the rendering; this makes it easier, if necessary you can get more renderings	26	26
■ length=27cm	26	27
■ how many pins and model name?	26	28
■ Thyracont exact model is in one note	27	29
■ how many pins and model name? MIL Type C connector	27	30

¹	■ MIL 19 C	27
²	■ we also used thin Kapton insulated BNC cable	27
³	■ Viton, maybe also describe the specification of these type of seals	27
⁴	■ rod length?	27
⁵	■ rod length? check Solid works	28
⁶	■ screwed / with a counter nut	28
⁷	Figure: Image of CRT mounting mechanism.	28
⁸	■ in general make better section titles	28
⁹	■ this is not so much of a leak but mainly outgassing / how was the pressure measured?	28
¹⁰	■ of a sufficient current	31
¹¹	■ with a sufficient small enough bandwidth	31
¹²	■ Optional: insert Foto of CRT's deflection plates - fig:DeflectionSetup	31
¹³	■ what happens when there is no bias voltage, what is the purpose of it	31
¹⁴	■ to achieve what	31
¹⁵	■ Find out which amplifier	33
¹⁶	■ which model?	33
¹⁷	■ which model?	33
¹⁸	■ Check amplifier specifications	33
¹⁹	■ Optional: Go to the lab and measure their performance with an Oszi.	33
²⁰	■ Insert fotos of finished circuits in housings	34
²¹	■ Optional: Go back to the Lab, set up the whole thing and look at its performance on the oszi	34
²²	■ picture placement and caption is missing	34
²³	■ skip: around and not all choose the wire path to ground	36
²⁴	■ caption missing	40
²⁵	■ shortly reference to the existing one we built and how to change it	42
²⁶	■ Check whether we have explained the benchmarks for the beam (waist, current, frequency)	42