

Exercises on Emittance measurements

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Abstract

In linear accelerators or transfer lines 4 main methods are used for emittance evaluation:

- The phase space scan
- The pepperpot method
- The 3 profiles method
- The quadrupole scan.

During a former workshop on beam diagnostics at the US particle accelerator school (USPAS) an optical bench has been used to simulate the last three of these methods. Unfortunately it will not be possible to demonstrate the setup for logistical reasons, however we can use previously acquired measurements to perform the data evaluation on them and thus understand the principle of these measurements in an accelerator.

Getting the software to work

Before starting the real work we have to get the system environment and the evaluation programs to work. First we will download and install an IDE (Integrated Development Environment) which allows us to compile and run the evaluation programs in a simple way.

First create a directory named *asp2014* in your home directory. The commands to be issued are printed in blue.

```
mkdir -p $HOME/asp2014/software
```

```
cd $HOME/asp2014/software
```

Then download *qtcreator-1.3.1.tar.gz* from Indico. The file will go to *\$HOME/Downloads*

Then uncompress the downloaded file into the directory previously created:

(in *\$HOME/asp2014/software*)

```
tar zxvf $HOME/Downloads/qtcreator-1.3.1.tar.gz.
```

You will find the binary *qtcreator* in *\$HOME/asp2014/qtcreator-1.3.1/bin*.

Then download and unpack *optic.tar.gz* from Indico in the same way. This will create a directory *optic* in *\$HOME/asp2014/*.

Now we can give it a first try: Type (in `$HOME/asp2014/software`)

`qtcreator-1.3.1/bin/qtcreator` and the IDE should start up. You may also include the binary directory in your execution path:

`export PATH=$PATH:$HOME/asp2014/software/qtcreator-1.3.1/bin` in which case typing: `qtcreator` will suffice. Putting the export command into `$HOME/.bash_profile` will make this permanent.

Once `qtcreator` is started, select File -> Open File or Project and select `optic.pro` in `$HOME/asp2014/software/optic`. Clicking the triangles allows you to have a look at the source code.

Click the upper green triangle on the bottom left side of `qtcreator` to compile and run the program.



Figure 1: optic program at work

If you get this far, you are in business! Now you can download and unpack the other tar files into the `src` directory and compile them the same way with `qtcreator`.

As alternative (and for those of you who prefer the command line) you may enter `$HOME/asp2014/software/optic` and the type:

`qmake`

`make`

`optic`

Now download and unpack all the other `xxx.tar.gz` files.

The last tar file to be downloaded is the `measurements` folder. Uncompress it in `$HOME/asp2014`.

Exercises

There is one exercise per method of emittance measurement.

Let's start with the most complex algorithm, the one that evaluates the Pepperpot measurement.

1. PEPPERPOT EVALUATION

There are 3 pepperpot measurements in the measurements folder.

Which of these measurements correspond to

- a diverging beam
- a converging beam
- an approximately parallel beam?

How can you tell and which orientations have the corresponding emittance ellipses?

2. *How to go about it?*

Start the QPepperpot program either through *qtcreator* or manually. Read-in the image of the pepperpot plate (`$HOME/asp2014/measurements/pepperpot/ppplate.bmp`) in order to calculate the scaling factor and the center position. The pepperpot holes have a distance of 1 mm. Note the corresponding values in *Settings -> Configure Pepperpot*. You may leave the *Distance PP Plate to Screen* at 0. This value is needed to calculate absolute angles but for the moment the program uses relative angles only.

Then you may read-in the first measurement. Switch all options in *Tools* off. Push the *Projections* button and you will get the projection of the image onto the X axis. You will see, that the spectrum is slightly noisy. Select *Show raw* and *Show filtered* to see the raw data and the low pass filtered data in the same plot. If the peaks are clearly visible select *Automatically find peaks* and *Show peaks* in the *Tools* menu. You may push the *Copy to manual Peaks button* and see the values found in the *Settings -> Configure Pepperpot* box. Then you may switch off the *Automatically find peaks* option and make minor manual corrections. Finally select the *Tools->Emittance* button to see the 3d emittance plot.

3. THE 3 - PROFILE METHOD

With this method 3 or more profiles are measured at different positions in the beam line and the beam width is determined. The beam width corresponds to 2 vertical lines in the phase space diagram (a fixed position and all angles). If we transform these lines back to the point where the first profile has been taken, then the lines are inclined and they are asymptotes to the

emittance ellipse at the position of the first profile. (Have a look at the emittance.docx file where you find a more detailed description)

Pick up the image files in measurements/3profiles. The filename contains information about the distance to the first profile (p20.bmp means that this image has been taken 20 mm downstream the first profile). Use the QProfile program to extract the (beam) spot size for each of the images.

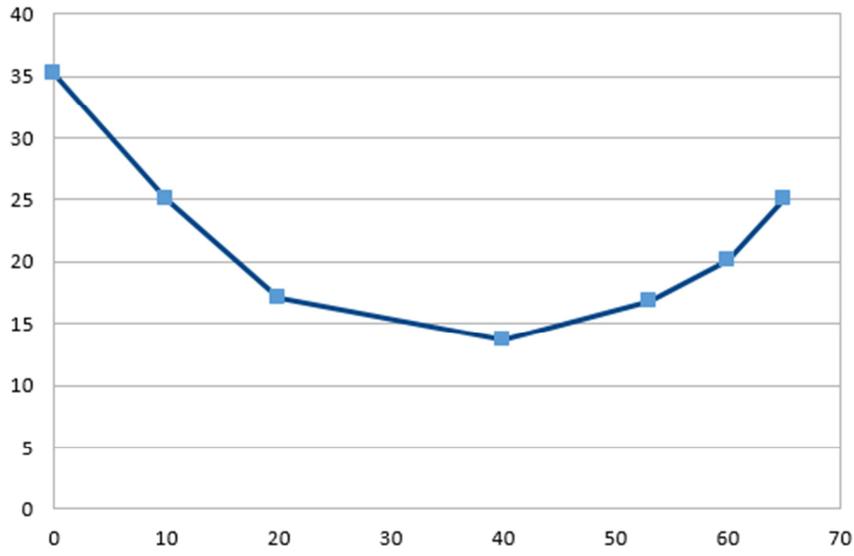


Figure 2: Fitted beam width at different positions

This size determines the vertical lines we have to transform back to the first profile, which is done with the optic program. Calculate the beam width at the first profile for an angle of “1”. This gives us the first of 2 points necessary to determine the inclined line. As the point with angle 0 is a fix-point under the transformation (no magnet element in the beam line means: no change in angles and no angle means: no change in position), we have the 2 points needed to draw the line at the position of the first profile. Do this for all images.

Then use the drawEmittance program to first draw the lines and finally hand-fit an ellipse.

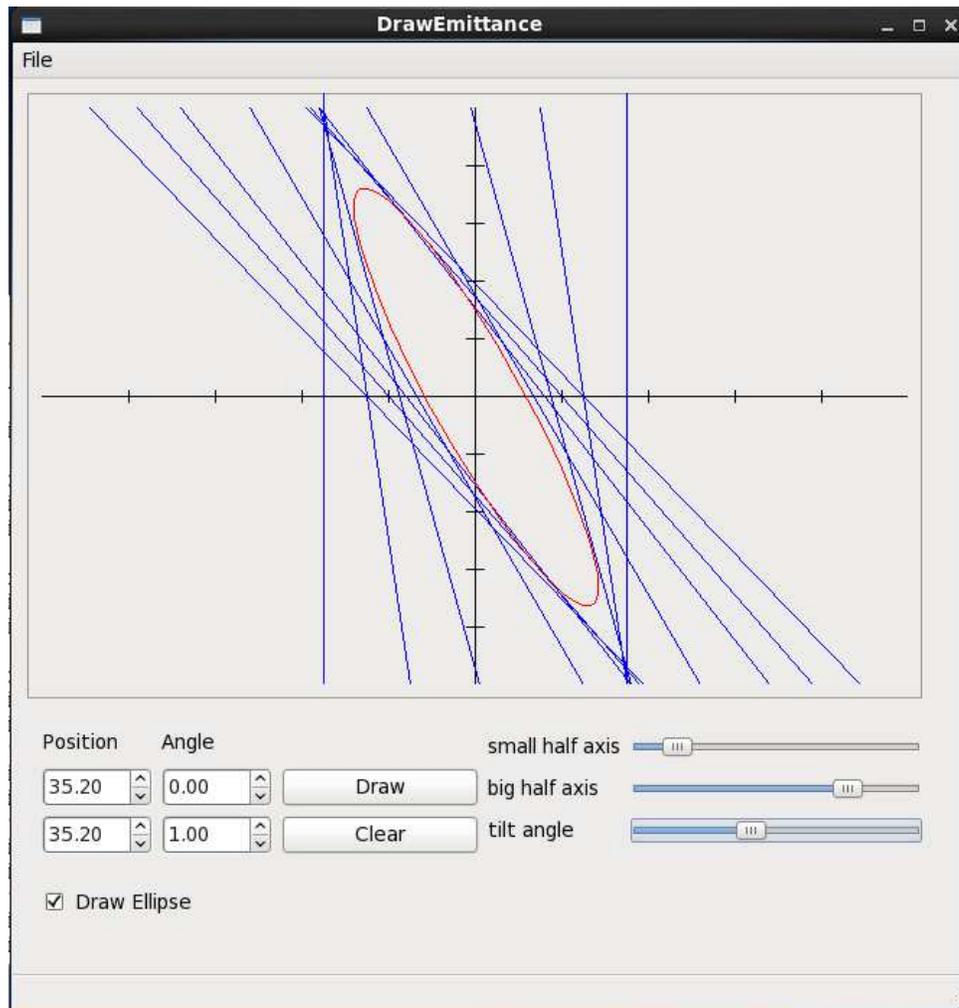


Figure 3: Emittance ellipse at first profile

4. THE QUADRUPOLE SCAN

The quadrupole scan uses different quadrupole strength to focus the beams at positions before and after the plane in which beam spots are measured. Using the transfer matrices associated with the quadrupole and a drift space to the plane in which the image is taken, one can again calculate the emittance. When moving the beam focus from a focal point after the measurement plane to one before the measurement plane, the beam spots decrease in size until the focal point lies in the measurement plane and increase again afterwards.

The mathematics for the quadrupole scan is again explained in emittance.docx.

Like in the exercise before, determine the beam spot sizes for each image in the measurements/quadsfan folder and use the quadScan program to plot the result.