LEP note 630

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# SOFTWARE FOR INJECTION STEERING

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Some application programs were written , for commissioning purposes , for steering the beam entering LEP. As these programs are not of fundamental importance for operation , no effort has been put by the group in charge of the application programs to make them operational. Nevertheless they may present an interest to maximise the injection efficiency when the dynamic aperture is small. This is why they have been put in a state where they can be used. Some more work is needed to make them operational.

Presently there exist an interface based on DIALOG which was implemented in 1989 by A. Artero which makes it possible to optimise the steering of the injected beam. The processes involved in this have been analysed in the frame of the AAWG ( secretary J. Poole ). They are :

- Inject on Central Orbit

- Optimise Injection by Steering the Transfer

The purpose of this note is to explain what these programs do and how to use and modify them.

## 1 Numerical procedures involved in the injection steering.

### 1.1 Fitting an orbit measurement.

This is the basic procedure. For a given set of trajectory measurements , it computes three constants which makes it possible to represent at best these measurements by means of a betatron oscillation ( minispec 2.4 in Inject on Central Orbit ). The expression measurement means here either a trajectory measurement or the difference between a trajectory and a closed orbit measurement. Indeed , as it is never possible to make the closed orbit distorsion zero , the best way to inject particles is to launch them as close as possible to the actual closed orbit.

The general expression of the transverse position of a particle in a circular machine is :

$$y_i = \sqrt{\beta_i}[acos\mu_i + bsin\mu_i] + D_i\frac{\delta p}{p} \quad (1)$$

$\beta_i$ is the value of the $\beta$-function , $\mu_i$ is the betatron phase and $D_i$ is the dispersion at the orbit monitor of index i. Such an expression is based on uncoupled optics. The values of a b and $\frac{\delta p}{p}$ are determined by means of a least-square-fit algorithm followed by an analysis of the measurement validity ( in order to discard wrong measurements ).

The principle of the least-square-fit algorithm is to find values of the constants which minimise the expression :

$$\sum_i [y_{im} - y_{ic}]^2$$

Where $y_{im}$ is the measured value and $y_{ic}$ the computed one by means of (1). The summation is performed over a relevant set of measurements. The minimisation condition is that the partial derivatives w.r.t. a b and $\frac{\delta p}{p}$ are made to vanish. This condition leads to the set of 3 linear equations with three unknowns :

$$\frac{\delta p}{p}\sum_i D_i^2 + a\sum_i D_i\sqrt{\beta_i}sin\mu_i + b\sum_i D_i\sqrt{\beta_i}cos\mu_i = \sum_i D_i y_{im}$$

$$\frac{\delta p}{p}\sum_i D_i\sqrt{\beta_i}sin\mu_i + a\sum_i \beta_i sin^2\mu_i + b\sum_i D_i\beta_i cos\mu_i sin\mu_i = \sum_i y_{im}\sqrt{\beta_i}sin\mu_i$$

$$\frac{\delta p}{p}\sum_i D_i\sqrt{\beta_i}cos\mu_i + a\sum_i \beta_i sin\mu_i cos\mu_i + b\sum_i D_i\beta_i cos^2\mu_i = \sum_i y_{im}\sqrt{\beta_i}cos\mu_i$$

Once a , b and $\frac{\delta p}{p}$ have been computed , the r.m.s. of the measurements is computed by :

$$y_{rms} = \sqrt{\frac{1}{n-1}\sum_i [y_{im} - y_{ic}]^2}$$

Then the measurements of index i for which

$$| y_{im} - y_{ic} | > 2y_{rms}$$

are removed from the list of valid measurements and the computation is redone without them. This is repeated until no measurement is discarded.

## 1.2 computation of a compensation.

Any sort of compensation can be computed by specifying that the sum of the oscillation amplitudes given by (1) and that due to the compensators is zero evrywhere in the machine.

As an example , we compute the increment of displacement and angle which have to be done at the place of the Lambertson magnet at the LEP entrance in order to cancel the vertical oscillation of the particles injected in LEP. This is a procedure used because the transfer lines and the machine were built in different divisions , and the person in charge of the transfer line provided this procedure to steer the injected beam. The procedure which has to be launched from the SPS control system is called : "orthogonal steering". The oscillation amplitude associated with the displacement $y_l$ and angle $\theta_l$ done at the point of index $l$ is given , at the place where the $\beta$-function has the value $\beta$ and the betatron phase the value $\mu$ , by :

$$y_l\sqrt{\frac{\beta}{\beta_l}}\left[cos(\mu-\mu_l)+\alpha_l sin(\mu-\mu_l)\right]+\theta_l\sqrt{\beta\beta_l}sin(\mu-mu_l)$$

we add to this the computed oscillation amplitude , i.e. :

$$\sqrt{\beta}[acos\mu+bsin\mu]$$

and we express that the sum is zero whatever $\mu$ and $\beta$. This provides the linear system to compute $y_l$ and $\theta_l$ :

$$y_l\left[cos\mu_l-\alpha_l sin\mu_l\right]-\theta_l\beta_l sin\mu_l+a\sqrt{\beta_l}=0$$

$$y_l\left[sin\mu_l+\alpha_l cos\mu_l\right]+\theta_l\beta_l sin\mu_l+b\sqrt{\beta_l}=0$$

A similar calculation can be done for the cases where the compensation is done by means of two angles. This is done for instance for the injection on central orbit or for the calculation of the closure of the injection bump.

Another example is the optimisation of the angle of the septum in order to minimise the horizontal amplitude of the injected particles. In this case , we want that the sum :

$$\theta_s\sqrt{\beta\beta_s}sin(\mu-\mu_s)+a\sqrt{\beta}cos\mu+b\sqrt{\beta}sin\mu$$

be minimum , as there is only one parameter available. This is achieved by expanding this expression in $cos\mu$ and $sin\mu$ and minimising the sum of the squares of their coefficients , i.e. :

$$\left[\theta_s\sqrt{\beta_s}cos\mu_s+a\right]^2+\left[-\theta_s\sqrt{\beta_s}cos\mu_s+a\right]^2$$

The minimum occurs for :

$$\theta_s=\frac{(asin\mu_s-bcos\mu_s)}{\sqrt{\beta_s}}$$

## 2 Practical implementation.

The numerical calculations described above have been implemented in a C program the source of which is in the file :

/user/lepaw/src/injection/inject_c.dir/newadjin.c

The sub-directory /user/lepaw/src/injection/inject_c.dir contains a makefile for the compilation of this program. There is also in this subdirectory :

- a C program used to modify the settings of the injection kickers : setk.c. This program has probably to be corrected for being usable because it has not been updated since the last system change.

- an orbit file with zero's everywhere used to compute the steering when no closed orbit measurement is available.

The steering computation is launched in the control system by invoking : inject_menu. All the necessary files involved in this process can be found in the main directory :

/user/lepaw/src/injection

A listing is given in table 1.

The other sub-directory : /user/lepaw/src/injection/injection_libs contains the general purpose functions :

- rcolel.c : reads the columns for a given element in a TFS table

- readtwel.c : reads the TWISS parameters for a given element in a given TFS TWISS file

- setzerocol.c : writes zero's in a given column of a given TFS table

- writek.c : writes strengths parameters in a given TFS stengths table

There is also a makefile to compile these functions.

The main directory : /user/lepaw/src/injection contains also the files used by DIALOG to provide injection_menu as well as a general makefile which can compile everything when a modification of any of the above functions has been modified and installs the modified executables in the LEP control system./pa- When making a modification it is safe :

- to compile it at first in its own directory in order to remove the bugs

- to test it in the main directory by invoking :

  make ' CXFLAGS = ' clear all

- to install it in the system by invoking :

  make clear all install

It is then possible to check the execution of injection_menu while staying in the main directory.

## 3 Present status of the injection software

It is possible to perform all the calculations needed to steer the injected beam. However the DIALOG interface is not working properly and it is safer to click systematically on the wanted options.

There is a bug in setk which prevents from sending the computed voltages to the injection kickers.

Practically the calculations have to be done as follows :

- put youself in the closed orbit directory of the day and measure a closed orbit. If it is not possible to do the measurement , the option ' zeros ' will have to be chosen in the ' compute menu '
- put the stopper 143 in order to make sure that the BOM will measure the first turn trajectory
- measure a trajectory ( this is the key measurement )
- invoke injection_menu
- clic on 'compute' and then on 'archived' ( trajectory ) ; 'archived' or 'zeros' ( closed orbit ). In the other boxes of the menu all choices are possible. It is usually useful to look at the optics informations to check that the measurements are correct. The selection on the names of the beam position monitors makes it possible to select either the first or the second ECA downstream the injection point.
- apply the corrections either by clicking ' apply ' and reading them , or by choosing the 'print' option in the 'compute' menu ( in this case you get it on the printer ).

## 4 Conclusion

It is presently possible to optimise the steering of the injected beam at the LEP entrance , so that the beam enters as close as possible to the closed orbit.

This may improve the injection efficiency when the steering of the transfer lines has been redone or when LEP is in a state such that its dynamic aperture is low. This is more accurate than the inspection of the screens at the LEP entrance.

The instructions in this note should be sufficient to make this optimisation , althought the interface is in a bad state.

```
sys5_bogota_lepaw_122>ls -lR
total 120
-rwxr-xr-x    1 lepaw    lep          39616 May  4 08:16 inject.dps
drwxr-xr-x    1 lepaw    lep           1024 May  4 10:58 inject_c.dir
-rwxr-xr-x    1 lepaw    lep           3215 Apr 12 10:00 inject_dia.c
-rwxr-xr-x    1 lepaw    lep           1680 Apr 12 10:00 inject_dia.h
-rwxr-xr-x    1 lepaw    lep           2880 Apr 12 10:00 inject_dia_ex.h
-rwxr-xr-x    1 lepaw    lep          25718 May  4 08:02 inject_dia_func.c
-rwxr-xr-x    1 lepaw    lep            874 May  4 08:33 inject_dialog.h
-rwxrwxr-x    1 lepaw    lep          33926 May  4 10:45 inject_dpd.obj
drwxrwxr-x    1 lepaw    lep           1024 May  4 10:58 injection_libs
-rwxr-xr-x    1 lepaw    lep           1880 May  4 10:56 makefile
-rwxr-xr-x    1 lepaw    lep           4290 Apr 12 10:00 standard_ui.dps

./inject_c.dir:
total 88
-rwxr-xr-x    1 lepaw    lep            224 Apr 12 09:59 help
-rwxr-xr-x    1 lepaw    lep            708 May  4 09:58 makefile
-rwxr-xr-x    1 lepaw    lep          44007 Apr 12 10:45 newadjin.c
-rwxr-xr-x    1 lepaw    lep          30811 Apr 12 10:00 orbzero
-rwxr-xr-x    1 lepaw    lep           9343 May  4 10:16 setk.c

./injection_libs:
total 11
-rwxrwxr-x    1 lepaw    lep            621 May  4 10:42 makefile
-rwxrwxr-x    1 lepaw    lep           1325 May  4 10:23 rcolel.c
-rwxrwxr-x    1 lepaw    lep           4418 May  4 10:23 readtwel.c
-rwxrwxr-x    1 lepaw    lep            945 May  4 10:43 setzerocol.c
-rwxrwxr-x    1 lepaw    lep           1946 May  4 10:23 writek.c
```

List of the files in the directories used by the injection software

Table 1

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