

Status of Reference Network Simulations

John Dale

ILC-CLIC LET Beam Dynamics Workshop

23 June 2009

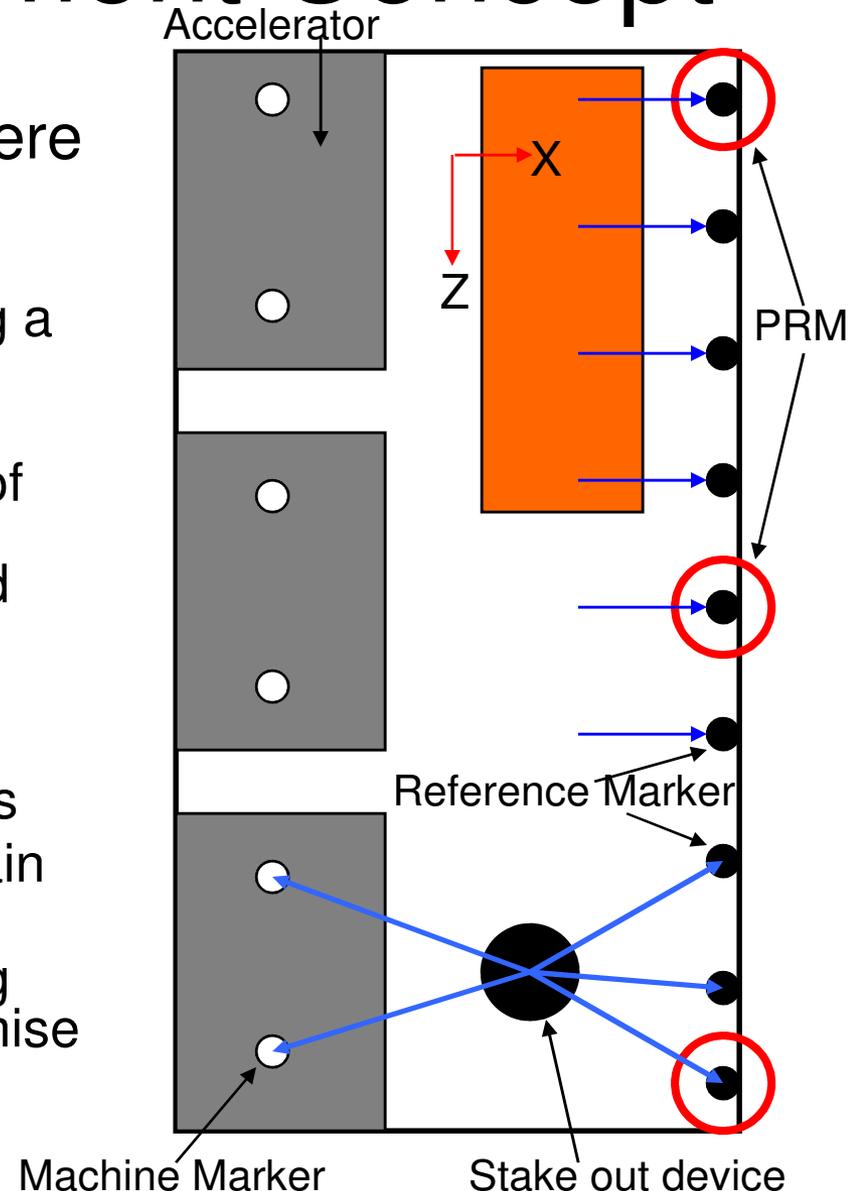


Introduction

- Alignment Concept
- Summary Of Previous Talks
 - Linear model
 - Free network solution
- Problems with model
 - Too simple
 - Generation of constraints
- Solutions to Problems
 - 4 marker network
 - EVD to determine eigenvectors
- Updated model comparison with panda
- Future Work

Accelerator Alignment Concept

- Many possible ways to Align an Accelerator, the concept used here is:
 - Over lapping measurements of a network of reference markers using a device such as a laser tracker or a LiCAS RTRS
 - Measurements of a small number of Primary Reference Markers (PRM) using, for example GPS transferred from the surface.
 - Combining all measurements in a linearised mathematical model to determine network marker positions
 - Using adjusted network to align Main Linac
 - Using Dispersion Matched Steering (DMS) to adjust correctors to minimise emittance



Reference Network Simulation Aims

- Generate ILC reference network solutions which can be used for LET simulations
- Easy to use
- Quickly (minutes not days)
- Correct statistical properties
- Capable of simulating existing as well as novel network measurement techniques

Possible Approaches

- Commercial survey adjustment software
 - Expensive
 - Need to be survey expert to use
 - Usually only use laser tracker/tachometers
- Full simulation of a specific device
 - Slow to generate networks
 - Restricted to one measurement technique
- Simplified Model
 - If designed correctly can be quick
 - Can be used to model novel devices

Simplified Model

- Have a device model
 - measures small number of RMs e.g. 4
 - moves on one RM each stop and repeats measurement
 - rotates around the X and Y axis
 - determines vector difference between RMs
 - only the error on the vector difference determination is required as input
- PRM measurements are vector difference measurements between PRM's

The Linearised Model

- M device stops, N reference Markers Total, O PRMs Total, device measures 4 markers per stop
- Measurement Vector L
 - Contains device and PRM vector differences
- Measurement Covariance Matrix P
 - Simple diagonal matrix assuming no cross dependency on measurements
- Variables Vector X
 - Contains all the markers positions
- Prediction Vector $F(X)$
 - Predicts L
- Difference Vector $W = F(X) - L$
- Design Matrix $A = \delta F(X) / \delta X$

The Linearised Model

- Normal Non-linear least squares minimises $W^T W$ leading to an improvement of estimates given by

$$\Delta X = -(A^T P A)^{-1} A^T P W$$

- Problem $A^T P A$ is singular and not invertible
- Model Requires Constraints.

Free Network Constraints

- Five constraints required
- Could constrain first point to be at (0,0,0) and both the rotations of first stop to be 0.
 - Gives zero error at one end and large error at other. Not the desired form
- Use a free network constraint
 - Technique developed in Geodesy
 - The free network constraint is that $X^T X$ is minimised.
 - If $X^T X = \min$ the trace of the output covariance matrix is also minimised
 - Equivalent to a generalised inverse
 - The least squares minimises $W^T W$ and $X^T X$ to give a unique solution

Free Network Constraints

- In a free network, the least squares solver is of the form

$$\Delta X = - \begin{bmatrix} A^T P A & A_2^T \\ A_2 & 0 \end{bmatrix}^{-1} \begin{bmatrix} A^T P W \\ 0 \end{bmatrix}$$

- Errors are of the form

$$\Sigma_X = \begin{bmatrix} A^T P A & A_2^T \\ A_2 & 0 \end{bmatrix}^{-1}$$

- Need to determine A_2^t and A_2
- A_2^t and A_2 are the matrix of eigenvectors corresponding to the zero (or small) eigenvalues

Free Network Constraint

- Break Up $A^T P A$ into sub-matrices

- N_{11} Must be non-singular

- N_{22} size 6×6

$$A^T P A = \begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix}$$

- Leading to constraint Matrix A_2

$$A_2 = ((N_{11}^{-1} N_{12})^T - I)$$

Model Summary

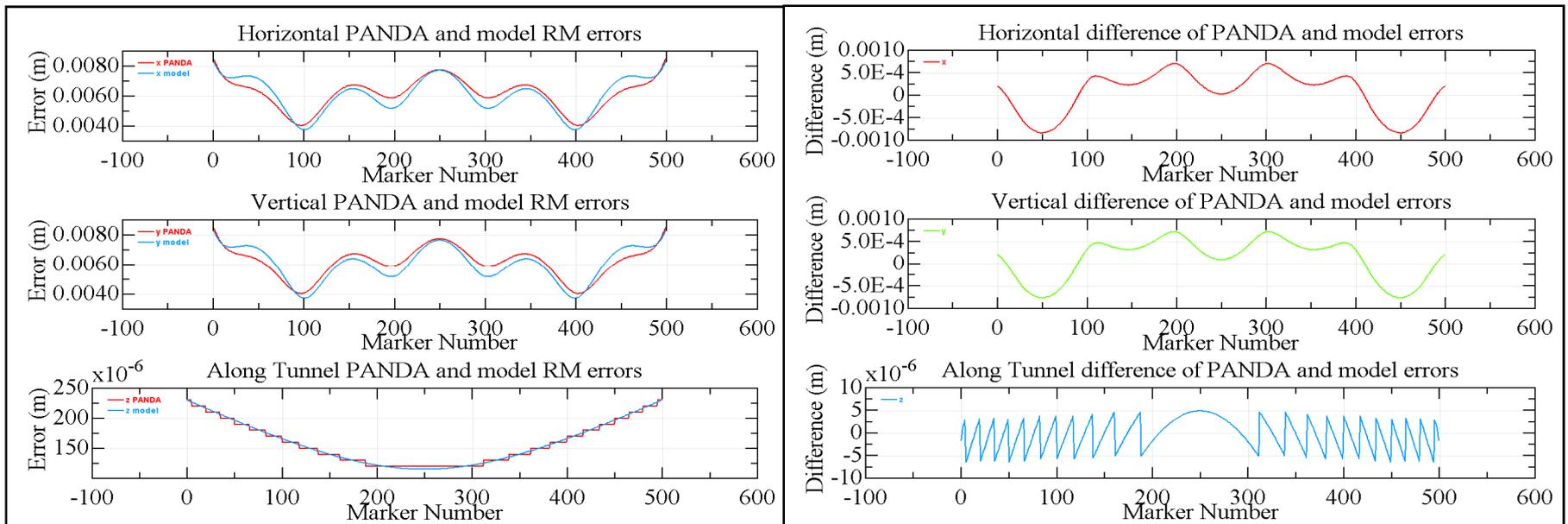
- Input
 - Device Measurement Errors
 - Number RMs measured by device in one stop
 - PRM Measurement Errors
 - Network Parameters
 - Number RMs, Number PRMS, RM spacing, PRM spacing
- Output
 - Reference marker position difference from truth
 - Reference marker position statistical error

Laser Tracker Network Simulation

- Test model by comparing to laser tracker network
- Can simulate ILC laser tracker networks using PANDA
- Use PANDA output to determine model parameters
 - minimising the difference between the PANDA statistical errors and the model statistical errors
 - Minimiser can adjust the model input parameters
 - minisation using JMinuit

Problems with previous version

- Had model which solved, but error curves didn't match PANDA



Problems

Two problems with model

1) The network was too simple

- A single line of points did not give sufficient strength to the network

2) Method of determining eigenvectors

- Method used only works for very well behaved matrices

Solutions

1) The network was too simple

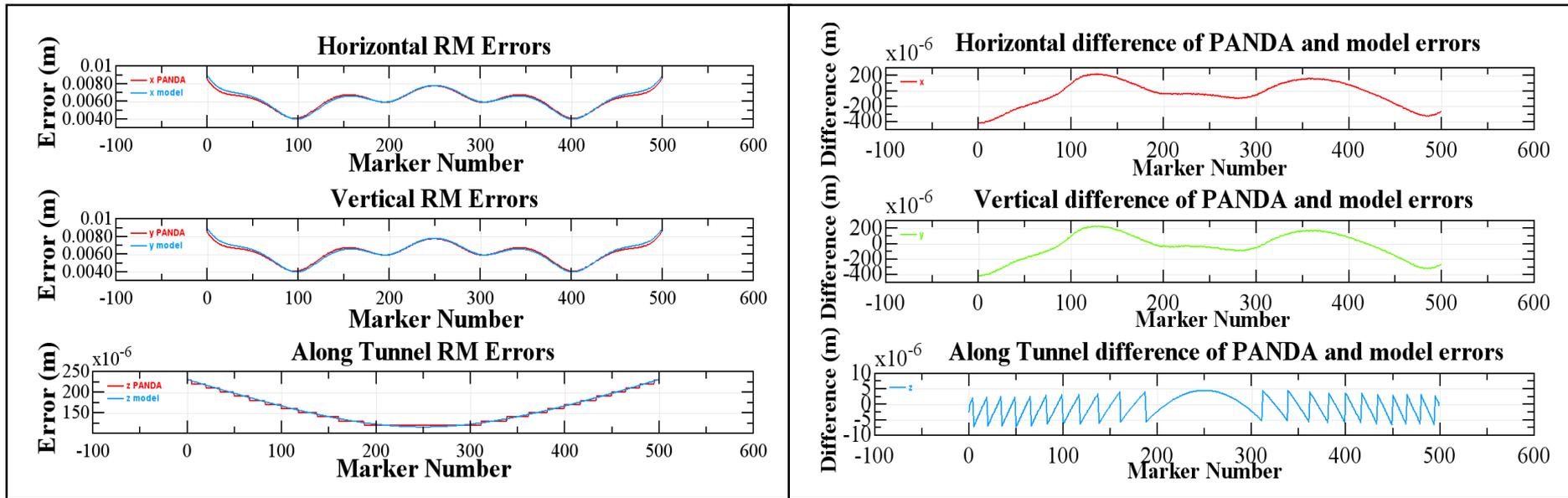
- Allow more complex 3D networks to be used
- Simulations now use four markers in a ring

2) Method of determining eigenvectors

- Determine the eigenvectors using more complex methods such as Eigen Value Decomposition (EVD)

Model vs PANDA

- Much better match between the PANDA and Model error curves



Model Status

- How to determine constraints better understood
- Determination of constraints is slow, especially on the full networks
 - EVD generates all eigenvalues and eigenvectors
 - One eigenvalue for each element in the network
- 40 minutes for a single iteration
- Many iterations required for solution

Future Work

- Determine required eigenvectors faster
 - Only require 6 eigenvectors, corresponding to the small eigenvalues.
- Test updated model with DMS simulations
- Distribute code