The Physics Behind the IQM Signal

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Presentation Goals:

• Describe the calculation model for IQM in terms of the physical characteristics and behavior of linear accelerators
  – Outline the basis of the calculation
  – Review the approximations in the model
  – Present data on the level of agreement
What inputs are expected?

• Predict the signal from IQM chamber based on:
  – Chamber characterization
  – Treatment unit (Linac) characterization
    • Collimation attenuation
    • Fluence profiles
  – Patient treatment description
    • Both static field-in-field and dynamic delivery modes

• Prediction accuracy = error detection
  – Target 2% accuracy throughout…
Linac Properties & IQM Calculation

• **Scope of calculation**
  – Chamber description and response
  – Linac Models
    • Source description assumptions
    • Geometry approximations

• **Source Parameterization**
  – Propagation of fluence to IQM signal generation
IQM Chamber Properties

• Sloped electrode chamber
  – Spatial gradient = delivery position encoding

• Characterized by
  – Reference field normalization
  – Gradient (sensitivity) map
  – CSM, \( S_{IQM} \)
Linac Characterization

• Behaviour to capture:
  – Output change with field size
  – Radial Profile
  – Transmission through collimating elements

• Source Assumption
  – Primary point source
  – Extended secondary source
Fundamentals of Signal Calculation

• IQM Signal for a Segment:

\[ C_{IQM} = U \cdot AOF(x, y) \cdot \frac{N_{IQM}}{n \times m} \cdot \sum_{i,j} S_{IQM}(i,j) \cdot ((1 - f_s)I_P + f_sI_S) \]

- \( U \) = MU setting for segment
- \( AOF \) = output change with field size (residual…)
- \( \frac{N_{IQM}}{n \times m} \) = normalization (electrometer reading)
- \( I_P, I_S \) = primary and secondary source intensity matrix
- \( f_s \) = fractional contribution from secondary source
- \( S_{IQM} \) = chamber positional sensitivity matrix
Primary Source Intensity $I_P$

- Starts with open source profile
  - Assume radially symmetric intensity profile
  - Apply effect of collimation attenuation
  - Works on an area weighted average rather than an intensity to a point
Primary Source Modulation

• Area-Weighted Transmission through collimating elements subdivided in regions of transmission and time for each pixel:

\[
\bar{T} = \sum_{l}^{n} \sum_{m=1}^{n} T_m \cdot \int_{t_{l-1}}^{t_l} A_m(t) dt
\]

\[
\int_{t_{l-1}}^{t_l} A_m(t) dt = \left[ \frac{1}{3} \Delta v_x \Delta v_x t^3 + \frac{1}{2} (\Delta v_x \Delta s_y + \Delta v_x \Delta s_y) t^2 + \Delta s_x \Delta s_y t \right]_{0}^{t_l-t_{l-1}}
\]
Secondary Source

• Extended source geometry
  – Positioned at bottom of flattening filter
Secondary Source Modulation

- More complex geometry:
  - Non-divergence matched
  - Multiple off-axis sources
  - Complex element shape shading

- Simplify calculation:
  - Static “snapshot” calculation
  - Sampling point geometry
  - Layered collimating element
AOF Characterization

- Captures changes in output due to field size effects
- Derived from a series of rectangular field measurements
- Behaves as a “residual”
  - Some effects accounted for by extended source
  - Rederived for tweaks in source description & transmission
- Look-up according to average field width, length
Example of an IMRT Field Measurement

- Example of clinical IMRT field on a TrueBeam accelerator
  - Measurement corrected for daily output
  - Calculation shown for ±3% range
  - All segments < ±5% for 9 IMRT fields
Example of a VMAT Field Measurement

- Head and neck VMAT field on Varian TrueBeam
- Calculation shown with ±3% range
- Large deviations shown on a segment by segment basis
- Good agreement on cumulative basis
Algorithm Performance for IMRT Delivery

580 apertures on Elekta Agility

338 apertures on Varian Truebeam
Summary

• IQM Calculation has been presented
  – Includes characterization:
    • Primary point source (dynamic motion, divergence matched collimation)
    • Extended secondary source (Compton based, oblique transmission)
  – Measurements show good agreement with calculations

• Continuing work:
  – Refinement of AOF parameterization
  – Speed increases in calculation