

09PM  
GZ1659



# A dual assembly multileaf collimator for radiotherapy

**Peter Brian Greer, M.Sc (Dist.), M.A.C.P.S.E.M.**

*Supervisor:* Assoc. Prof. T. van Doorn

Department of Physics and Mathematical Physics

Adelaide University

*A thesis submitted in fulfilment of the requirements for the degree of Doctor of  
Philosophy, October, 2000*

# Table of contents

<b>1. INTRODUCTION</b>	<b>1</b>
1.1. Radiation Therapy	1
1.2. Multileaf collimators	2
1.3. Imaging to verify beam placement	2
1.4. Aims of this study	3
1.5. Outline of thesis	4
<b>2. MULTILEAF COLLIMATORS</b>	<b>7</b>
2.1. Introduction	7
2.2. Radiotherapy Beam Collimation	7
2.2.1. Beam production	7
2.2.2. Beam Collimation	8
2.2.2.1. Flattening filter	8
2.2.2.2. Beam Monitoring Chambers (BMC)	9
2.2.2.3. Secondary collimators	10
2.2.2.4. Tertiary Blocking	10
2.2.2.5. Multileaf Collimator	10
2.2.2.6. Light field	11
2.2.3. Dosimetric properties of radiotherapy beams	12
2.2.3.1. Percentage Depth Dose	12
2.2.3.2. Beam Penumbra	12
2.2.3.3. Output Factor	13
2.3. Design of Multileaf Collimators	14
2.3.1. Leaf Design	14
2.3.2. Collimator Geometry	16
2.3.3. Field shape configuration	16
2.4. Dosimetric Properties of Multileaf Collimators	17
2.4.1. Rectangular field penumbra	17
2.4.2. Angled edge penumbra	17
2.4.3. Methods to reduce dose undulation	21
2.4.4. Radiation transmission through MLC	21

2.4.5.	Percentage depth dose and output factors	22
2.4.6.	Light and radiation field coincidence	23
2.4.7.	Optimal orientation of leaves	24
2.4.8.	Setting leaf ends to target cross-section	24
2.5.	Acceptance Testing and Commissioning	26
2.5.1.	Mechanical acceptance and commissioning tests	26
2.5.2.	Leaf positioning with collimator rotation	26
2.5.3.	Leaf positioning with gantry rotation	27
2.5.4.	Coincidence of light field and x-ray field	27
2.5.5.	Leaf transmission	28
2.5.6.	Penumbra	29
2.5.7.	Dosimetric parameters	29
2.5.8.	Interlocks and file transfer	29
2.6.	MLCs and intensity modulated radiation therapy	30
2.6.1.	IMRT	30
2.6.2.	Static segmented method	30
2.6.3.	Dynamic sliding window method	31
2.6.4.	MLC tests for IMRT	33
<b>3.</b>	<b>MEGAVOLTAGE IMAGING</b>	<b>35</b>
3.1.	Introduction	35
3.2.	Theory of image formation	36
3.2.1.	Imaging system and image formation	36
3.2.2.	Contrast and signal-to-noise ratio	38
3.2.2.1.	Contrast	38
3.2.2.2.	Noise	40
3.2.2.3.	Scattered radiation	42
3.2.3.	Linear Systems Theory for imaging systems	45
3.2.3.1.	Point Spread Function (Impulse Response)	45
3.2.3.2.	Modulation Transfer Function (System Transfer Function)	47
3.2.3.3.	Line Spread Function	49
3.2.3.4.	Edge Spread Function	49
3.2.3.5.	Sampling	50
3.2.4.	Linear systems model for Spatial Resolution	52

3.2.4.1.	Effect of source on resolution	52
3.2.4.2.	Effect of Detector on resolution	54
3.2.4.3.	Effect of scatter on resolution	56
3.3.	Megavoltage Image Detectors	57
3.3.1.	Film/Screen	57
3.3.1.1.	Construction and image formation	57
3.3.1.2.	Characteristic (H-D) Curve	58
3.3.1.3.	Resolution	59
3.3.1.4.	Noise	60
3.3.2.	Video-camera based detectors	61
3.3.2.1.	Screen/Phosphor	61
3.3.2.2.	Optical chain	64
3.3.2.3.	Cameras	64
3.3.3.	Matrix-ion chamber device	65
3.3.4.	Scanning linear arrays	68
3.3.5.	Flat-panel devices	68
3.3.5.1.	Amorphous Silicon	68
3.3.5.2.	Amorphous selenium	69
3.3.6.	Lower energy imaging devices	70
3.4.	Image Processing	71
3.4.1.	Point Processing	72
3.4.1.1.	Background	72
3.4.1.2.	Image Negatives	72
3.4.1.3.	Contrast Stretching	73
3.4.1.4.	Compression of dynamic range	73
3.4.1.5.	Gray-level slicing	73
3.4.1.6.	Bit-plane slicing	73
3.4.1.7.	Histogram equalisation	74
3.4.1.8.	Local statistically based enhancement	78
3.4.1.9.	Image averaging	78
3.4.2.	Spatial Filtering	79
3.4.2.1.	Background	79
3.4.2.2.	Lowpass filtering (smoothing)	79

3.4.2.3.	Median filtering	80
3.4.2.4.	Highpass filtering	80
3.4.2.5.	High boost filtering	81
3.4.2.6.	Derivative filters	81
3.4.3.	Enhancement In The Frequency Domain	83
3.4.3.1.	Lowpass filtering	83
3.4.3.2.	Highpass filtering	84
3.4.4.	Image Restoration	85
3.4.4.1.	Degradation model (algebraic)	85
3.4.4.2.	Algebraic restoration	86
3.4.4.3.	Inverse filtering	87
3.4.4.4.	Least mean square (Wiener) filter	88
3.4.4.5.	Interactive restoration	88
3.5.	Clinical applications of portal imaging	89
3.5.1.	Types of images	89
3.5.2.	Determination of field placement	90
3.5.2.1.	Visual inspection	90
3.5.2.2.	Image Registration	90
3.5.3.	Correction of patient position	93
3.5.3.1.	Field Placement Errors	94
3.5.3.2.	Intra-fraction corrections	94
3.5.3.3.	Inter-fraction corrections (correction strategies)	95
<b>4.</b>	<b>EVALUATION OF AN ALGORITHM FOR THE ASSESSMENT OF THE MTF USING AN EDGE METHOD</b>	<b>99</b>
4.1.	Introduction	99
4.2.	Description of the MTF calculation algorithm	101
4.2.1.	Profile sampling	101
4.2.2.	Edge angle determination	103
4.2.3.	Profile Registration	103
4.2.4.	Smoothing	104
4.2.5.	Differentiation	104
4.2.6.	Folding	104
4.3.	Derivation of transfer function of profile registration	105

4.4. Theoretical transfer function of the algorithm	107
4.4.1. Sampling aperture	108
4.4.2. Profile Registration	109
4.4.3. Differentiation	110
4.4.4. Smoothing	110
4.4.5. Folding of the LSF	110
4.4.6. Frequency axis scaling	110
4.5. Transfer function evaluation	111
4.5.1. Sampling Aperture	112
4.5.2. Profile Registration	114
4.5.3. Smoothing, Differentiation, and Folding	119
4.5.4. Frequency axis scaling	121
4.6. MTF measurement and transfer function for a simulated image	121
4.7. MTF measurement for an experimental edge image.	124
4.8. Discussion	126
4.9. Conclusion	130
<b>5. A DESIGN FOR A DUAL ASSEMBLY MULTILEAF COLLIMATOR</b>	<b>131</b>
5.1. Introduction	131
5.2. Proposed Collimation Design and Imaging Procedure	133
5.3. Methods and Materials of Collimator Characterization	136
5.3.1. Relative dose determination	136
5.3.1.1. Film Linearity	136
5.3.1.2. Vidar pixel values to optical density	137
5.3.2. Individual slit-field profiles	138
5.3.2.1. Measurement	140
5.3.2.2. Analytical Modelling	141
5.3.3. Multiple slit profiles and images	142
5.3.4. Shielding transmission	145
5.3.4.1. Measurement	145
5.3.4.2. Analytical Modelling	147
5.4. Results	148
5.4.1. Individual slit-field profiles	148
5.4.1.1. Measurement	148

5.4.1.2. Analytical Modelling	153
5.4.2. Multiple slit profiles and images	156
5.4.2.1. Single Movement	156
5.4.2.2. Double-Movement	158
5.4.3. Shielding transmission	159
5.4.3.1. Measurement	159
5.4.3.2. Analytical Modelling	160
5.5. Discussion	161
5.6. Conclusion	163
<b>6. IMAGE FORMATION WITH A DUAL ASSEMBLY MULTILEAF COLLIMATOR DESIGN: IMAGE QUALITY</b>	<b>165</b>
6.1. Introduction	165
6.2. Theory	168
6.3. Measurement technique	173
6.4. Methods and Materials	176
6.4.1. Open field MTF	176
6.4.2. MTF comparison under open slits and leaves	177
6.4.3. Scatter	179
6.4.4. Magnification	180
6.4.5. Slit width	180
6.4.6. Source-collimator distance	181
6.4.7. Septal spacing	181
6.4.8. Energy	181
6.4.9. Contrast-noise ratio	182
6.5. Results	182
6.5.1. Open field MTF	182
6.5.2. MTF comparison under the open slits and under the leaves	182
6.5.3. Scatter	185
6.5.4. Magnification	186
6.5.5. Slit width	187
6.5.6. Source-collimator distance	188
6.5.7. Septal spacing	188
6.5.8. Energy	189

6.5.9. Contrast-to-noise ratio	190
6.6. Discussion	190
6.7. Conclusion	192
<b>7. IMAGE FORMATION WITH A DUAL ASSEMBLY MULTILEAF COLLIMATOR DESIGN: IMAGE PROCESSING</b>	<b>193</b>
7.1. Introduction	193
7.2. Theory	194
7.2.1. Spatial Domain	194
7.2.2. Frequency Domain	196
7.3. Methods	198
7.3.1. Spatial domain methodology	198
7.3.2. Frequency domain methodology	202
7.4. Results	203
7.4.1. Spatial domain	203
7.4.2. Frequency domain	209
7.5. Discussion	216
7.6. Conclusions	216
<b>8. PROPERTIES OF A PROTOTYPE DUAL ASSEMBLY MULTILEAF COLLIMATOR</b>	<b>219</b>
8.1. Introduction	219
8.2. Methods and Materials	220
8.2.1. MLC design and construction	220
8.2.2. Imaging Performance	222
8.2.3. Leakage	224
8.2.4. Penumbra	224
8.2.5. Field edge smoothing	225
8.3. Results	226
8.3.1. Imaging Performance	226
8.3.2. Leakage	228
8.3.3. Penumbra	230
8.3.4. Field Edge Smoothing	232
8.4. Discussion	232



8.5. Conclusions	234
<b>9. CONCLUSIONS</b>	<b>237</b>
9.1. Main findings	237
9.2. Future research	238
<b>REFERENCES</b>	<b>241</b>

## **Abstract**

Medical physics seeks to provide methods to improve radiation therapy for cancer treatment. A multileaf collimator (MLC) for radiation therapy has been designed that splits each leaf bank into two vertically displaced assemblies or levels with each level consisting of alternate leaves and leaf spaces. The leaves in the upper level shield the spaces in the lower level. Each level can shift laterally, in the direction perpendicular to leaf motion by one leaf width. Following lateral movement of one level, the leaves align with the other level and radiation is transmitted through the collimator as multiple slit fields in a grid pattern. This transmission can be used to form an image of the external anatomy and would enable rapid double-exposure portal images to be acquired during the treatment.

The radiation profiles transmitted for image formation through the collimator design were investigated to examine their dependence on the collimator design features. The slit or leaf width was found to have the major influence on the transmitted profiles. As the slit width decreases the profiles become broader than the geometric slit projection resulting in a modulated image of the external anatomy, rather than a sampled or 'grid' image. The shielding of this design was found to be adequate provided the leaf faces of the adjacent vertically displaced leaves are at least aligned, therefore an overlap or tongue and groove is not required.

To examine the image quality of the modulated images, an algorithm to calculate the modulation transfer function (MTF) from an edge object image was developed. The effect of the algorithm on the measured MTF was investigated. To examine whether the spatial resolution of the image due to the source (geometric unsharpness) varies for the regions under the slits and under the leaves MTF measurements were made. The regions under the leaves were found to show poorer spatial resolution due to the more peripheral (extra-focal) source view. Image processing techniques were developed to remove the modulation from the images, including spatial domain and frequency domain methods. Finally, a prototype dual assembly multileaf collimator was constructed and the imaging and shielding properties were investigated.