A MULTILEAF COLLIMATOR FOR NEUTRON RADIATION THERAPY*

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Abstract

A multi-leaf collimator (MLC) has been designed for installation on the super-conducting cyclotron at the Gershenson Radiation Oncology Center. This MLC will replace the existing multi-rod collimator and the increased efficiency thus achieved should allow for a 50% increase in the number of patients treated. A study of the penumbra region of the neutron beam with focused and unfocused collimator leaves has been completed, together with activation measurements in steel and tungsten. Results of these studies were used to finalize the collimator leaf design. A steel collimator leaf with a 5 mm projection at the isocenter and a wedge shaped section has been chosen, to provide beam divergence in the direction perpendicular to the leaf motion. The leaf profile is "stepped" to prevent neutron leakage. The rationale for this leaf design is discussed. The overall design of the collimator system and the incorporation of a remote wedge-changing device will be presented. Each leaf is positioned using a stepping motor; the leaf position is independently confirmed using an optical system incorporating a coherent fiber optic and a CCD camera. The control system is being designed to allow for the implementation of intensity modulated neutron radiation therapy (IMNRT).

1 INTRODUCTION

The motivation for developing a multi-leaf collimator (MLC) beam shaping device to replace the current multi-rod collimator (MRC) for the d(48.5)+Be produced neutron beam from the Harper Hospital super-conducting cyclotron [1] is primarily a 50% increase in efficiency over the current MRC. An additional goal for the computer controlled MLC will be to enable the development of intensity modulated neutron radiation therapy (IMNRT) treatments. Additional efficiency is desired because the cyclotron is currently at daily patient capacity. The efficiency increase will be achieved by reducing the amount of time to change field shape. Currently the MRC, a manual device, requires a radiation therapist to enter the treatment room to accomplish every field change. The computer controlled MLC will change shape faster and also reduce the radiation dose to therapists. IMNRT has the promise of combining the radio-biological advantages of neutron treatments with superior dose depositional characteristics (in comparison to traditional neutron therapy beams). This paper will discuss the MLC mechanical design, radiologic considerations, and the MLC control system.

2 MECHANICAL DESCRIPTION

2.1 General Properties

The MLC will be a singly focused design of 60 leaf pairs with the leaf planes perpendicular to leaf drive direction matching beam divergence on that axis. Each leaf will project 5 mm width at isocenter. The maximum field size at isocenter will be 30×30 cm^2. Each leaf will have the capability to travel entirely cross-field. Full drive across field allows tailoring of a target volume through which the axis of rotation does not pass [2].

2.2 MLC Leaf Design

The leaves will be fabricated from low-carbon 1010 steel. As reported elsewhere there is no discernable advantage other than required attenuation thickness for selecting tungsten over steel [3]. The disadvantage of using tungsten over steel is a factor of 10 in cost due to machinability and raw material costs. Individual leaf thickness varies from 0.145" at the top to 0.113" at the bottom, providing a total 9.45^o angle for the entire leaf stack matching radiation beam divergence. The gap between the plates is nominally 0.005". The thickness of the steel leaves is 30 cm, which allows 2.5% transmission. All leaves share common features of bearing surfaces on two edges, a cut-out slot for drive thread clearance, and a relieved area on both facing surfaces to accommodate adjacent plate drive thread clearance. The leaf features are depicted in figure 1. A nylon power nut is mounted in a milled detent at the entrance of the drive slot and secured by two steel tags. MLC leaves will be constrained by opposing Nylatron® bearings. The bearings are mounted in milled pockets in the ½" cap and 1½" bottom steel plates. Remaining structural elements consist of steel side-plates and end motor-plates. The base-plate is designed to be fit compatible with the current MRC base-plate

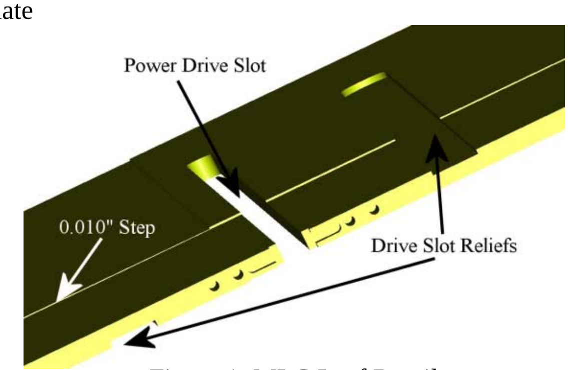

Figure 1: MLC Leaf Detail

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2.3 MLC Plate Coating

A MoS_2 based coating has been selected to reduce friction between adjacent MLC plates [4]. The coating is to be applied because of poor performance of the uncoated plates during mechanical wear testing in an 8-leaf testing model built to simulate MLC function. Running from the home (retracted) to maximum extension positions cycle tests on adjacent leaf pairs rapidly and severely galled the steel plates. The galling resulted in a halt of plate motion, and on one occasion resulted in a broken drive nut. Measurement on a precision plane table using a height gauge indicated leaf flatness 0.015”±0.005” whereas the nominal inter-leaf gap is 0.005”. Because leaf raw material flatness was confirmed to be 0.004”±0.001”, the out of flatness condition is attributable to leaf machining and most likely the result of cutting the drive thread clearance slot. The resulting condition is points of contact between adjacent leaf surfaces. Flattening the plate through a process such as electro-dynamic machining (EDM) or plate lubrication were both considered to be possible solutions to the contact problem. Lubrication in the form of a 0.0005” thin high-performance tetrafluorocarbon polymer coating was investigated. The coating performed very well over a six week, 110,000 cycle test. Unfortunately tetrafluorocarbon polymers similar to PTFE (Teflon®) reportedly break down in radiation environments leaching small molecules such as fluorine that in the presence of moisture can produce HFl acid [5]. The MoS_2 based coating was found to perform as well with higher radiation tolerance [6].

2.4 Wedges

Two tungsten beam modifying wedges, 45° and 60°, have also been incorporated into the MLC design. The wedges will translate in and out of the beam on a sled mechanism (figure 2) mounted on linear bearings. The wedge sleds seen in figure 2 include rotational ring drives that rotate the wedges in increments of 90°. The two wedges are shown mounted on plates affixed to the ring drive.

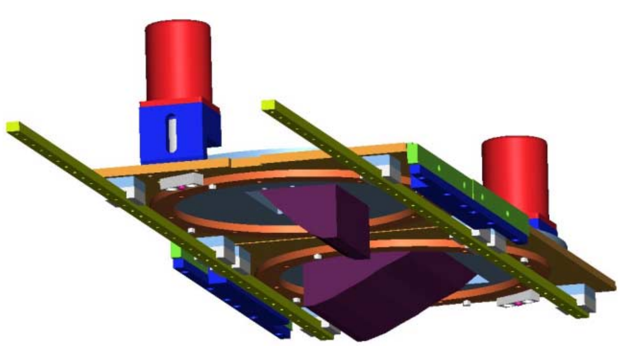

Figure 2: Wedges Translation and Rotation Mechanism

Once in position, the wedge sled is locked down by a steel pawl. The 45° tungsten wedge will be fabricated from 23 laminates of 1/8 inch thick tungsten. Two of the laminates are wider to create flanges that will be used to retain the wedge in the mating assembly.

2.5 Leakage Radiation Step

Because the MLC design is focused in one axis, the 0.005” gap between the leaves is aligned directly with the radiation source. Including 0.010” steps in the center of the leaves will minimize interleaf radiation leakage. A 0.020” clearance is provided for the step along the drive direction. Closed leaf pairs will be abutted outside the radiation field as defined by primary collimating jaws above the MLC.

3 CONTROL SYSTEM

A combination of hardware and software interfaced between the MLC, MLC control computer, and cyclotron control console will be required to provide system operation. The MLC Control System (MLCCS) will be responsible for setting required shapes on the MLC, and verifying those shapes to be accurate to within ±1 mm for each leaf’s projection in the plane perpendicular to beam axis at the position of the isocenter of gantry rotation. The MLCCS will consist of a motion control system to move the plates and wedges in and out of position, a machine vision system to provide independent verification of MLC leaf positions, and a cyclotron control interface capable of turning on and off the beam, as well as running as a slave to all current system interlocks. The control system will also be connected to the hospital wide area network (WAN) to facilitate downloading and uploading appropriate patient treatment data. The MLCCS custom software will be developed using National Instrument’s LabView™. Windows 2000 was chosen as the development platform in conjunction with a Dell Pentium III workstation with dual monitor support. A schematic of the MLCCS is presented in figure 3 showing system information flow.

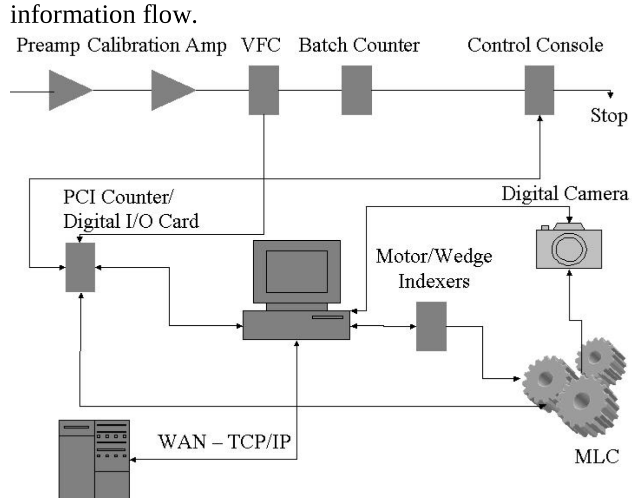

Figure 3: MLCCS Schematic

3.1 Motion Control

Leaf and wedge motion will be provided by precision high torque stepping motors. Motor control will be accomplished using digitally addressable indexers. Stepping motors require pulses of current and voltage to move. The motor indexers provide the drive pulses and are capable of receiving text-based instructions on a RS-422 party line serial communications link from the control computer. Because of the inherent 32 device limitation of the RS-422 protocol, four serial channels will be used simultaneously. The parallel architecture will also serve to speed up the overall system response time. MLC plate translation using the stepping motors has been verified to be accurate to within 0.001" in the testing model. An additional RS-422 connection will be used with indexers to control the motion of the wedge stepping motors.

3.2 Field Geometry Verification

The MLCCS will employ a machine vision system as the ultimate arbiter of plate positions. Although the positional resolution of the machine vision system will not be as high as the stepping motor drive accuracy, the machine vision system is able to ensure final plate position under failure conditions such as communication faults or mechanical malfunctions. This level of system verification is thought to be necessary considering that the radiation fields will be used in a medical venue. The vision system will also store a permanent record of field shapes used for each patient. The machine vision system will consist of a hi-resolution CCD digital camera interfaced to the MLC control computer as indicated in figure 3. The camera will view the MLC leaves through the existing light localizer assembly [7], which is used to project a field light on the patient coincident with the radiation field shape. The camera will be optically connected to the light localizer with a radiation tolerant quartz scope, providing a standoff distance of about 1 m for the camera from the radiation beam. Custom image recognition software developed using National Instrument's IMAQ software will interface directly with the MLC control software. The machine vision system will be software calibrated across the field of view (FOV), using a square grid pattern. Imaging high contrast targets on the ends of the leaves and comparing those positions to fixed benchmarks applied to the MLC frame will determine MLC plate positions. Measured leaf positions will be compared to desired leaf positions, and if they are in error by more than ±1 mm projected to the iso-centric plane, the MLC interlock will prevent treatment and signal for service. Leaf target identification will be accomplished by thresholding the raw image to remove everything except the targets and then using a "particle analysis" to identify each target and its location. The vision system will also be responsible for verifying and recording wedge inclusion and orientation.

3.3 Cyclotron Control Console Interface

The MLCCS will also interface to the current cyclotron control console, duplicating dose monitoring functions and acting as a slave to all current interlocks. Radiation dose monitoring is currently performed as depicted at the top of figure 3. Dose ionization chambers outputs are converted to voltages, and after amplification converted to frequencies. The frequency modulated (FM) signals are then put into pulse counters that count up to a pre-programmed level before terminating the beam. The MLCCS will duplicate the counting by pulling the FM signals off and running them through a PCI multi-channel counter card. The MLCCS and control console counters will be required to agree within 0.3%. Digital IO from the cyclotron console will also be routed through the counter card that includes IO ports. The digital signals IO to MLCCS will be "OK to treat", representing a clearance of all current system interlocks, and the ability to turn on and off the beam consisting of RF on/off, and source current on/off.

4 CONCLUSION

The neutron MLC design is nearly complete. Mechanical fabrication has begun along with development of the MLCCS. When installed later this year, the MLC will allow a 50% increase in patient load on the cyclotron at Harper Hospital as well as enabling the development of IMNRT.

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