Mechanical System Design

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ME 337

Under: Prof. Prabhat Munshi

1. Objectives

This project aims to design a medical CT scanner that optimizes image quality while minimizing radiation exposure and ensuring patient safety. The design should incorporate the balance of image resolution with radiation dose, improve scanning speed, and improving the overall user experience for patients and medical professionals.

2. System Description

The mechanical design of the CT scanner is based on a feasibility study that analyzed its engineering and operational characteristics. The scanner consists of several key components, including the radiation source, source holder, collimators, detectors, electronic signal processing system, bearings, and drive motor.

The scanner is designed for medical imaging and operates by rotating an X-ray source and detector array around the patient to create detailed cross-sectional images. It shares similarities with conventional CT scanners but has the following key characteristics:

- A high-energy X-ray source is used to penetrate the human body and provide clear imaging of internal structures.
- The scan time is optimized for rapid image acquisition to minimize patient exposure to radiation.
- Advanced radiation detection and signal processing techniques enhance image clarity and diagnostic accuracy.

The scanner consists of three main sections:

- **The Rotating Assembly:** Houses the X-ray tube and detector array, rotating around the patient to capture multiple projections.
- **The Stationary Mechanical Frame:** Provides structural support and stability to the system.
- **The Computer Control System:** Processes raw image data using reconstruction algorithms to generate high-resolution images.

The rotating assembly includes collimators and a source holder mounted within a circular steel plate. Bearings facilitate smooth rotation, while a precision motor drives movement. A secondary gear transmission system ensures controlled and stable rotation.

The scanner frame is constructed from stainless steel to maintain mechanical stability and minimize external radiation exposure. The patient table is designed for precise positioning and smooth movement in the gantry.

The total weight of the scanner, including the rotating assembly, detector array, motor, and structural components, is approximately 950 pounds.

3. Choice of X-ray source

We chose the 0.5 mm focal spot X-ray source due to its high-resolution imaging capabilities, which are essential for vascular and extremity applications. Its smaller size produces a finer X-ray beam, enhancing image sharpness and spatial resolution, which improves the visibility of small vessels and subtle tissue details.
Spellman MMB125PN3.5 Monoblock®, with its <1ms rise time and pulsed fluoroscopy, allows rapid image acquisition with reduced patient dose, ensuring efficiency and safety. This makes the 0.5mm focal spot an optimal choice for precise medical imaging.

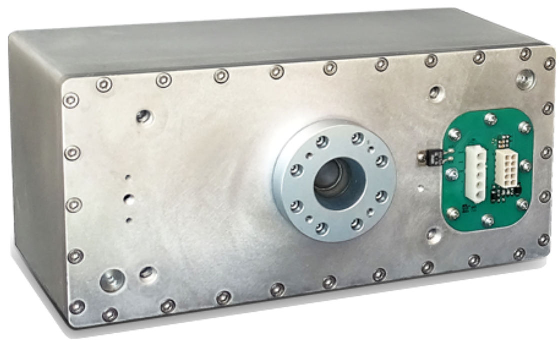

Figure 1. *MMB125PN3.5 Medical MONOBLOCK*

4. Choice of X-ray Detector

We chose the Hamamatsu S11299-321 photodiode array due to its superior performance in X-ray non-destructive inspection of fast-moving objects, making it an excellent fit for real-time medical imaging applications. The array features:

- **GOS ceramic scintillator**, offering low afterglow and minimal crosstalk, ensuring sharp and accurate image capture.
- **High sensitivity and broad spectral response** (340 to 1100 nm), enabling effective detection of X-rays across a wide range of energies.
- **Compact, slender form factor** (25.4 mm × 10.2 mm), making it ideal for integration into the detector assembly of the CT scanner without adding bulk.

These characteristics enhance the system's detection accuracy and image clarity, making the S11299-321 an optimal choice for precise and efficient CT imaging.

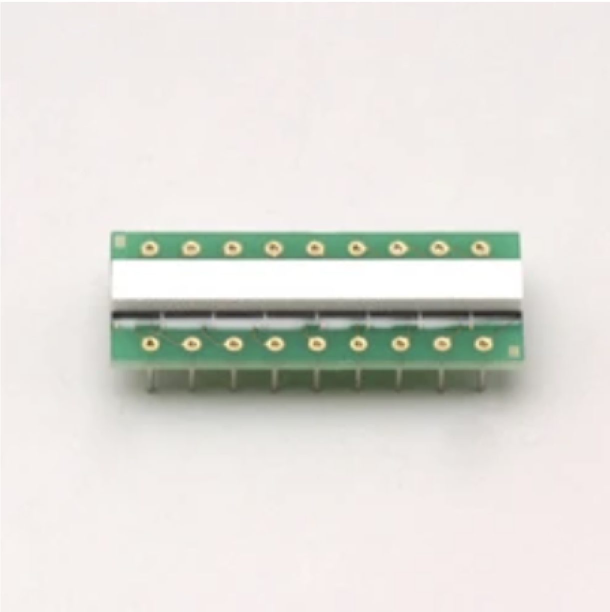

Figure 2. *Hamamatsu S11299-321*

5. Design

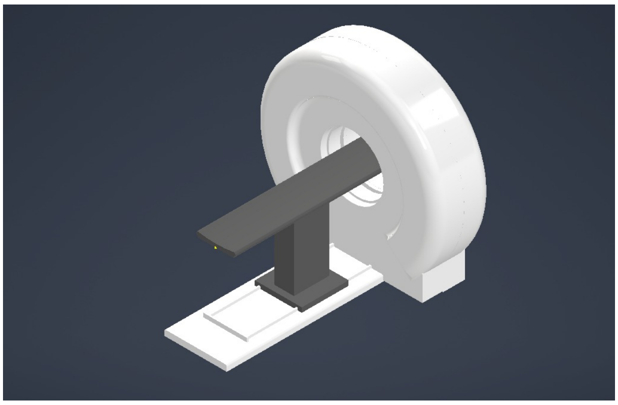

Figure 3. *CT design*

We have provided the design of each component used in the CT scanner.

5.1. Source

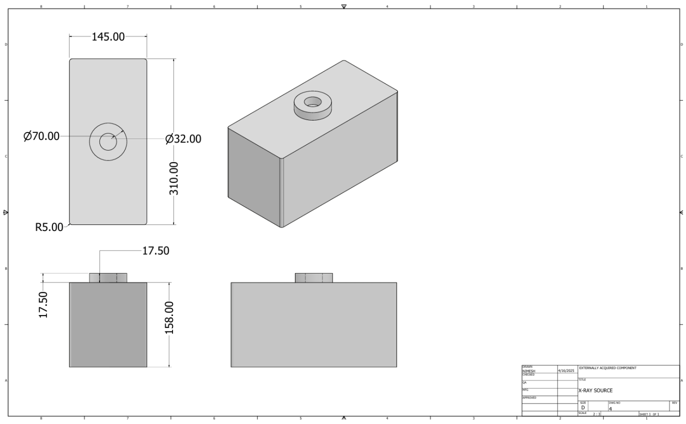

Figure 4. *Source*

5.2. Detector

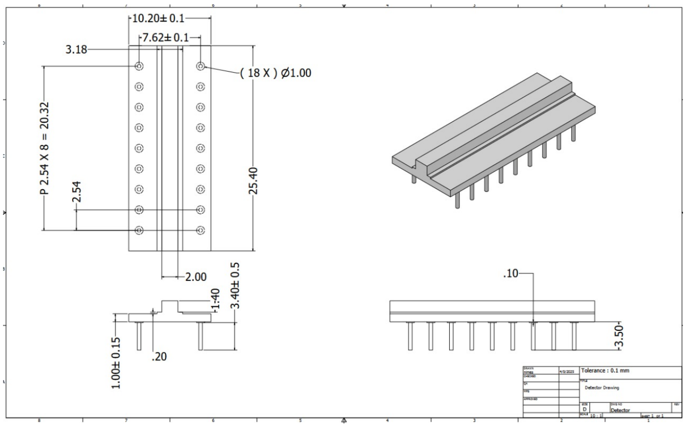

Figure 5. *Detector*

5.3. Patient Table

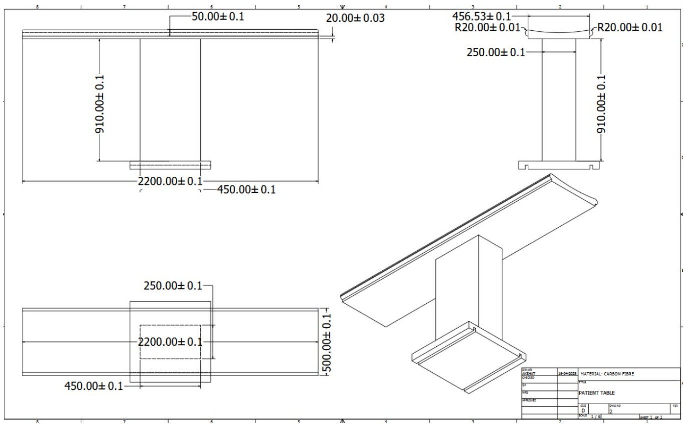

Figure 6. *Patient Table*

5.4. Rotating Gantry

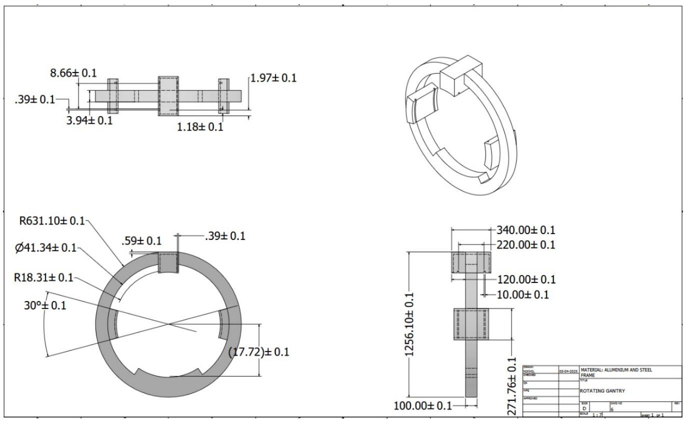

Figure 7. *Rotating Gantry*

5.5. Gantry Back Cover

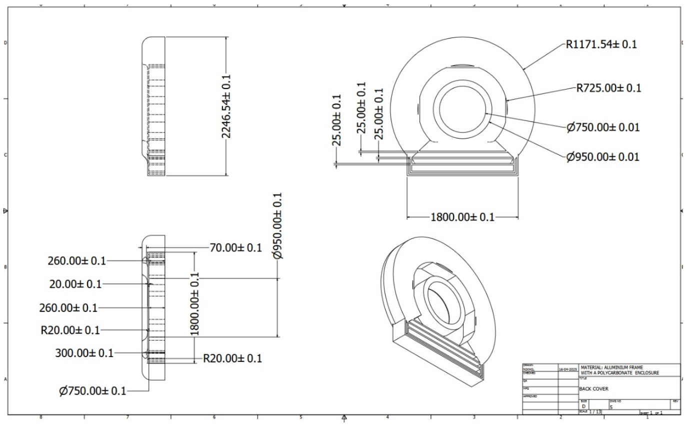

Figure 8. *Gantry Back Cover*

5.6. Gantry Support

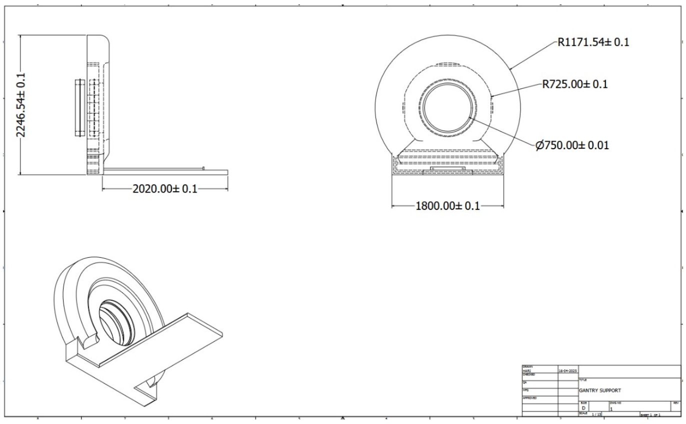

Figure 9. *Gantry Support*

6. Choice of Material

1. **Source:** Bought externally.
2. **Detector:** Bought externally.
3. **Patient Table:**
   Carbon Fiber Composite is the preferred material for CT scan patient tables due to the following advantages:
   - **Superior Imaging Quality:** High uniformity and low impurity levels ensure clearer images and more accurate diagnoses.
   - **Reduced Radiation Exposure:** Excellent X-ray transmittance lowers patient radiation dose.
   - **Structural Benefits:** High strength-to-weight ratio minimizes deflection while keeping the table lightweight.
   - **Ease of Patient Handling:** Supports smooth loading and unloading procedures.
   - **High Weight Capacity:** Can support up to 660 lbs, suitable for bariatric patients.
4. **Rotating Gantry:**
   Carbon Fiber Reinforced Polymer (CFRP) is the best choice for the rotating gantry due to the following reasons:
   - **Lightweight for Fast Rotation:** CFRP has an excellent strength-to-weight ratio, reducing the moment of inertia and enabling quicker, smoother rotations—ideal for high-speed CT scanning.
   - **High Stiffness and Low Deflection:** The material offers minimal deflection under load (as low as 200 μm), ensuring accurate alignment of imaging components and high image quality.
   - **Vibration Damping:** CFRP provides superior natural frequency damping, reducing motion artifacts and enhancing image stability during rapid gantry movement.
   - **Thermal Stability:** Its low thermal expansion makes CFRP suitable for controlled hospital environments, maintaining mechanical precision over time.
   - **Compact and Modern Design:** Enables sleek, space-efficient gantries, ideal for modular CT systems in modern healthcare settings.
5. **Gantry Back Cover:**
   Polyethylene (PE) and **Polyurethane (PU)** are commonly used materials for CT gantry back covers, each offering distinct advantages:
   - **Polyethylene (PE):**

- **Advantages:** Latex-free, transparent, and designed for single-use applications.
- **Features:** Includes adhesive strips for secure attachment and is contoured to fit the gantry surface.
- **Best For:** Quick clean-up and protection from patient fluids, ideal for disposable covers in contamination-sensitive settings.

- **Polyurethane (PU):**
  - **Advantages:** Highly durable and tear-resistant, suitable for repeated use.
  - **Features:** Easy to clean without leaving residue.
  - **Best For:** Long-term protection of equipment from fluids and prevention of infection spread.

Material selection depends on use case: PE is ideal for disposable, contamination-sensitive situations, while PU is preferred for reusable, long-term protection.

6. **Gantry Support:**
   High-Strength Steel Alloys are primarily used for CT gantry support structures due to:

   - **Structural Rigidity:** Maintains precise alignment during high-speed rotation (up to 30 RPM) and tilting (±30°).
   - **Load-Bearing Capacity:** Supports the weight of rotating components (X-ray tube, detectors, collimators) and the patient table.
   - **Vibration Dampening:** Minimizes resonance from rotational forces, critical for image clarity.

7. Product Specifications

Table 1: X-Ray Source – Spellman MMB125PN3.5

Parameter	Specification
X-ray Tube	Spellman MMB125PN3.5
Voltage Range	40–125 kV
Power	Peak: 3500 W, Average: 600 W
Focal Spot	0.5 mm (small), 1.6 mm (large)
Target Material	Tungsten
Target Angle	16°
Beam Filter	0.8 mm Al
X-ray Rise Time	<1 ms
Anode Heat Capacity	35.5 kJ (675 kHU)
Anode Heat Dissipation	600 W
Leakage Radiation	<1 mGy/hr @ 1 m
Detector Type	Back-illuminated Si photodiode

Table 2: Detector – Hamamatsu S11299 Series

Parameter	Specification
Photodiode Array	16-element
Scintillator Options	CsI(Tl), GOS ceramic, Phosphor sheet
Operating Temp.	−10 to +60 °C
Storage Temp.	−20 to +70 °C
Scanner Speed	30 RPM
Drive Motor	Variable speed, 1.5 HP induction (example)
Power Transmission	Gear or belt
X-Ray Tank	310 × 158 × 145 mm, 13 kg
Operating Temp.	0 to +40°C (source), −10 to +60°C (detector)
Storage Temp.	−20 to +70°C
Humidity	5–95%, non-condensing
Altitude	0 to 2438 m
Radiation Dose Rate	<5 mRem/hr @ >3 inches
Resolution Elements	130 (example)
Density Resolution	0.03 g/cm^3
Max Count Rate	10^5 cps

8. System Calibration and Operation

The system should be calibrated using a set of density standards ranging from 0 to 1 g/cm^3. This process ensures that the reconstructed density maps are both accurate and consistent.

A computer manages all aspects of system operation automatically, including data collection, calibration, scan timing, motor speed, image reconstruction, and storage. Operators interact with the system through a keyboard terminal.

9. Results and Discussions

The detailed animations are uploaded in the link given below. LINK

10. Learning Outcomes

11. Acknowledgments

We thank Prof. Prabhat Munshi for successfully teaching us the principles for conducting this experiment. Their expertise and support immensely helped us.

We would also like to thank IIT Gandhinagar for providing us with the platform and support necessary to conduct this experiment.

Lastly, we would like to thank our peers, whose continued support was instrumental in completing this experiment successfully.

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