MAGIS-100 Laser Transport Vacuum Simulations and LED Atom Tracker

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Background

- Matter-wave Atomic Gradiometer Interferometric Sensor
 - Dark matter and new forces
 - Advancing quantum science
 - Gravitational wave detector development
- Atom interferometry

Atom Source Photo: Stanford University

100m shaft Sr atoms will traverse

My Projects

- Vacuum Simulations for the Laser Transport System (LTS)
 - Compare low conductance designs of lens mounts
 - Characterize pressure profile of the LTS

Ion Pump Photo: Ideal Vacuum Products

Laser Transport System

- LED Atom Tracker
 - Propose materials to implement in the project
 - Design software for the different science modes

Arduino Uno and LED strip simulation
Photo: How To Mechatronics

Vacuum Simulations for the Laser Transport System (LTS)-Purpose

- Ensure vacuum system has low enough pressure to meet experimental requirements

Vacuum Simulations for the Laser Transport System (LTS)-Procedure

1. Create vacuum tube in NX

2. Find conductance in Molflow

Node B	x	y	z	Element	Element Length (m)	Element Name	Element ID Number	ID Number	Cross Sectional Area (m ² /Perimeter of Vacuum piece)	ANSYS Conductance (m ³ /s)	Element Name
1	0.00	0.00	0.00	HVTube	1	1	1	8	0.4732	0.7150	HVTube
2	0.17	0.00	0.00	HVTube	2	2	2	1	1.0000	0.0900	Ion Pump
3	0.33	0.00	0.00	HVTube	3	3	3	4			
4	0.50	0.00	0.00	HVTube	4	4	4	5			
5	0.66	0.00	0.00	HVTube	5	5	5	6			
6	0.83	0.00	0.00	HVTube	6	6	6	7			
7	1.00	0.00	0.00	HVTube	7	7	7	8			
8	1.16	0.00	0.00	HVTube	8	8	8	9			
9	1.33	0.00	0.00	Ion Pump	9	9	9	10			

Node	x	y	z	Item	Element	Node A	Node B	Pump (Y or N)	Node Input (4)	Element Input	Pump Input (8)	Element Loads (Tor*10 ¹⁰ /m ²)	Element Loads (Pa*cm ²)
1	0.00	0.00	0.00	HVTube	1	1	2	N	N3.0.0.0	E3.2		6.70E-13	8.9326E-10
2	0.17	0.00	0.00	HVTube	2	2	3	N	N3.0.16614775.0.0	E3.3		6.70E-13	8.9326E-10
3	0.33	0.00	0.00	HVTube	3	3	4	N	N3.0.3322955.0.0	E3.4		6.70E-13	8.9326E-10
4	0.50	0.00	0.00	HVTube	4	4	5	N	N3.0.49844325.0.0	E3.5		6.70E-13	8.9326E-10
5	0.66	0.00	0.00	HVTube	5	5	6	N	N3.0.664591.0.0	E3.6		6.70E-13	8.9326E-10
6	0.83	0.00	0.00	HVTube	6	6	7	N	N3.0.83073875.0.0	E3.7		6.70E-13	8.9326E-10
7	1.00	0.00	0.00	HVTube	7	7	8	N	N3.0.9968865.0.0	E3.8		6.70E-13	8.9326E-10
8	1.16	0.00	0.00	HVTube	8	8	9	N	N3.1.16309425.0.0	E3.9		6.70E-13	8.9326E-10
9	1.33	0.00	0.00	Ion Pump	9	7	10	Y	N3.1.33.0.0	E7.10	0.10,Temp.0		
10	1.00	-1.00	0.00	Ion Pump	9	7	10	Y	N3.1.1.0	E7.10	0.10,Temp.0		

3. Complete spreadsheet with nodes and conductance data, spreadsheet format courtesy of Jesse Batko, Fermilab

4. Convert vacuum units to thermal units and generate code

Vacuum Simulations for the Laser Transport System (LTS)-Procedure

Run 1										Run 2									
Dist	Pressure (Pa)	Pressure (Torr)	Dist	Pressure (Pa)	Pressure (Torr)	Dist	NODE	TEMP		NODE	TEMP		NODE	TEMP		NODE	TEMP		NODE
0.00	1.16E-05	8.67E-08	0.00	1.16E-05	8.67E-08	0.00	1	1.16E-05		1	1.16E-05		1	1.16E-05		1	1.16E-05		1
0.17	1.15E-05	8.66E-08	0.17	1.15E-05	8.66E-08	0.17	2	1.15E-05		2	1.15E-05		2	1.15E-05		2	1.15E-05		2
0.33	1.15E-05	8.64E-08	0.33	1.15E-05	8.64E-08	0.33	3	1.15E-05		3	1.15E-05		3	1.15E-05		3	1.15E-05		3
0.50	1.15E-05	8.60E-08	0.50	1.15E-05	8.60E-08	0.50	4	1.15E-05		4	1.15E-05		4	1.15E-05		4	1.15E-05		4
0.66	1.14E-05	8.55E-08	0.66	1.14E-05	8.55E-08	0.66	5	1.14E-05		5	1.14E-05		5	1.14E-05		5	1.14E-05		5
0.83	1.13E-05	8.48E-08	0.83	1.13E-05	8.48E-08	0.83	6	1.13E-05		6	1.13E-05		6	1.13E-05		6	1.13E-05		6
1.00	1.12E-05	8.39E-08	1.00	1.12E-05	8.39E-08	1.00	7	1.12E-05		7	1.12E-05		7	1.12E-05		7	1.12E-05		7
1.16	1.12E-05	8.41E-08	1.16	1.12E-05	8.42E-08	1.16	8	1.12E-05		8	1.12E-05		8	1.12E-05		8	1.12E-05		8
1.33	1.12E-05	8.42E-08	1.33	1.12E-05	8.42E-08	1.33	9	1.12E-05		9	1.12E-05		9	1.12E-05		9	1.12E-05		9
Max:		8.67E-08	Max:		8.67E-08														
Min:		8.39E-08	Min:		8.39E-08														
Avg:		8.54E-08	Avg:		8.54E-08														

5. Run thermal simulation in ANSYS

6. Convert data back to vacuum

7. Plot pressure distribution

Vacuum Simulations for the Laser Transport System (LTS)-Variables

Middle mirror box's orifice

Ion pump speed and placement

Vacuum Simulations for the Laser Transport System (LTS)-Results

LED Atom Tracker-Purpose

- Allow spectators to see where the Sr atoms are while the experiment is running
- Public outreach

Programmable LEDs in action

Where is the Sr?

LED Atom Tracker-Procedure

The function DelayTime[MaxHeight_,LEDDensity_] calculates a function to implement into the code using the height and LED density of the LED strips:

n^{th} LED time of 1st flash = 102.041 [9.89949 - Re[$\sqrt{98. - 0.326667 n}$]] milliseconds

n^{th} LED time of 2nd flash = 1010.15 + 58.3212 $\sqrt{300 - n}$ milliseconds

n^{th} LED delay time = -102.041 Re[$\sqrt{98. - 0.326667 n}$] + 102.041 Re[$\sqrt{98.3267 - 0.326667 n}$] milliseconds

Minimum delay time (bottom of trajectory) = 1.68 milliseconds

Maximum delay time (top of trajectory) = 58.3 milliseconds

1. Calculate atoms' trajectory, Mathematica Notebook courtesy of Sam Carman, Stanford

3. Create program in Arduino Integrated Development Environment (IDE)

```
LEDAtomTracker\ArduinoMode\
#include <Adafruit_NeoPixel.h>
#include <math.h>

#define LED_PIN 2

#define LED_COUNT 300 // 300 LEDs in 5m
Adafruit_NeoPixel strip(LED_COUNT, LED_PIN, NEO_GRB + NEO_KHZ800);
void setup()
{
  strip.begin();
  strip.setBrightness(255);
  strip.show(); // initialize all pixels to off
}

void loop()
{
  for (int n = 0; n < LED_COUNT; n++) {
    double wait = 102.041*(9.89949-sqrt((98.0-0.326667*n)));
    strip.setPixelColor(n, 255, 255, 255);
    strip.show();
    delay(wait);
    strip.clear();
  }
}
```

Arduino IDE output:

```
Uploading...
Uploading: [Progress bar] 100% 0.45s
Verifying...
Verifying: [Progress bar] 100% 0.45s
Done uploading.
```

4. Connect Arduino to LED strip

2. Design in TinkerCAD

LED Atom Tracker- Procedure

5. Run the Circuit

LED Atom Tracker- Results

- 5m segment complete
 - Software programs
 - Stable Connections
 - Start on button press
- Power requirements
- Recommendations on how to scale

```
LEDAtomTrackerScienceMode2 5
#include <Adafruit_NeoPixel.h>
#define LED_PIN 2

#define LED_COUNT 300

// declare neopixel strip object:
Adafruit_NeoPixel strip(LED_COUNT, LED_PIN, NEO_GRB + NEO_KHZ800);

void setup() {
  // put your setup code here, to run once:
  strip.begin();
  strip.setBrightness(127);
}

void loop() {
  // put your main code here, to run repeatedly:
  scienceMode2();
}

void scienceMode2() {
  double wait = 5.0;
  for (int i = 0, j = 200; i < 50; i++, j++) {
    strip.fill(strip.Color(127,0,0), i, 3);
    strip.fill(strip.Color(0,0,127), j, 3);
    strip.show();
    delay(wait);
    strip.clear();
  }
}
```

Done uploading.
bvrduke done. Thank you.

Science mode 2 program

Circuit starting
on button press

LED Atom Tracker- Future

- Scale up to 100m
 - Power injection
- Safety specifications
- Software for all science modes

Connection for power injection

MAGIS-100 Collaborators