MAGIS-100 Laser Transport Vacuum Simulations and LED Atom Tracker

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Vacuum Simulations on the Laser Transport System (LTS)

Purpose

MAGIS-100 uses atom <u>م</u> interferometry to measure the distance between the Sr atoms traversing the shaft. The laser must travel through vacuum to measure accurately. Project ensures the vacuum system has low enough pressure to Laser goes through the LTS to the top of the shaft meet experimental requirements.



Inside look at the LTS

LED Atom Tracker

Purpose

Where is To allow spectators to see where the Sr the Sr? atoms are while the experiment is running.



Procedure



1. Create vacuum tube in NX





2. Find conductance in Molflow

| | | Note . | ts Help | |
|---------|---|------------------------------------|----------------------|----------|
| d | Share 💭 Comments | Solution is done! | 1 1 ⁵ 2 1 | |
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| | 🐓 🔊 • | Close | | |
| | Ideas Sensitivity | | | |
| | | Main Menu 🛞 | ANCVC | 1- 2 |
| | * | Preferences NODAL SOLUTION | ANSIS | 😧 3 - |
| | 0 | B Solution | лп. 7 2020 | 😝 😜 |
| 'cm^2)) | Element Loads (Pa*m/: | B General Postproc | 15:01:35 | |
| | 8.9326E-10 | B TimeHist Postpro | | |
| | 8.9326E-10 | B Radiation Opt BMX = .116E-04 | | |
| | 8.9326E-10 | A PRNSOL Command | × | |
| | 8.9326E-10 | File | | |
| | 8.9326E-10 | DETAT TEME NODAL SOLUTION DED NODE | | |
| | 8.9326E-10 | PATH TERP RODE SOLUTION PER RODE | | |
| | 8.9326E-10 | LOAD STEP= 1 SUBSTEP= 1 | | |
| | | TIME- 1.0000 LOAD CASE- 0 | | Q |
| | | NODE TEMP 1 0.11558E-004 | | 2 |
| | | 2 0.11548E-004 3 0.11517E-004 | | • |
| | | 4 8.11465E-004 5 8.11393E-004 | | Q |
| | | 6 0.11301E-004 7 0.11188E-004 | | 40 |
| | | 9 8.11227E-004 | | |
| | | MAXIMUM ABSOLUTE VALUES | | |
| | | NODE 1 VALUE 0.11558E-004 | | |
| | | | | |
| | | | | 80 |
| | | | | |
| | 10 A | | MIN | <u>@</u> |
| | _ | | | |

| (B) | | | | | | | | | | | | | | | | | | |
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| 1 z | Node B | x | у | z | Element | Element Length (in) | Element Length (m) | Element Name | Element ID Number | ID Number | | | Cross Sectional Area (m ²)(Perimeter of Vacuum piece) | ANSYS Conductance (m ² /s) | Element Name | | | |
| 2 0 | 2 | 0.17 | 0 | 0 | 1 | 6.54125 | 0.17 | HVTube | 1 | 1 | 8 | | 0.4732 | 0.7150 | HVTube | | | |
| 3 0 | 3 | 0.33 | 0 | 0 | 2 | 6.54125 | 0.17 | HVTube | 1 | 2 | 1 | | 1.0000 | 0.0300 | Ion Pump | | | |
| 4 0 | 4 | 0.50 | 0 | 0 | 3 | 6.54125 | 0.17 | HVTube | 1 | | | | | | | | | |
| 5 0 | 5 | 0.66 | 0 | 0 | 4 | 6.54125 | 0.17 | HVTube | 1 | | | | | | | | | |
| 6 0 | 6 | 0.83 | 0 | 0 | 5 | 6.54125 | 0.17 | HVTube | 1 | | | | | | | | | |
| 7 0 | 7 | 1.00 | 0 | 0 | 6 | 6.54125 | 0.17 | HVTube | 1 | | | | | | | | | |
| 8 0 | 8 | 1.16 | 0 | 0 | 7 | 6.54125 | 0.17 | HVTube | 1 | | | | | | | | | |
| 9 0 | 9 | 1.33 | 0 | 0 | 8 | 6.54125 | 0.17 | HVTube | 1 | | | | | | | | | |
| 10 0 11 | 10 | 1.00 | -1 | 0 | 9 | 39.37 | 1.00 | Ion Pump | 2 | | | | | | | | | |

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

| Paste 🗳 Form | | | | | | | | Format Cell Insert D as Table Styles | | | |
|---------------|---------------|-----------------|------|---------------|-----------------|------|-------|---|---|-------|----------|
| A1 0 × | → fx B | c | D | F | F | 6 | н | | 1 | ĸ | 1 |
| 1 | | | | | | | Run 1 | · | | Run 2 | |
| 3 | Einal E | actus Run A | | Einal E | actus Rup B | | | | | | |
| 5 Dist | Pressure (Pa) | Pressure (Torr) | Dist | Pressure (Pa) | Pressure (Torr) | Dist | NODE | TEMP | | NODE | TEMP |
| 6 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 |
| 7 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 |
| 8 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 |
| 9 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 |
| 10 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 |
| 11 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 |
| 12 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 |
| 13 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 |
| 14 1.33 15 | 1.12E-05 | 8.42E-08 | 1.33 | 1.12E-05 | 8.42E-08 | 1.33 | 9 | 1.12E-05 | | 9 | 1.12E-05 |
| 16 | Max: | 8.67E-08 | | Max: | 8.67E-08 | | | | | | |
| 17 | Min: | 8.39E-08 | | Min: | 8.39E-08 | | | | | | |
| 18 | Avg: | 8.54E-08 | | Avg: | 8.54E-08 | | | | | | |
| 19 | | | | | | | | | | | |
| 20 | | | | | | | | | | | |
| 21 | | | | | | | | | | | |
| 22 | | | | | | | | | | | |

Procedure

Use classical physics to model the atoms' trajectory and implement in a software program

| | The function DelayTime[MaxHeight_,LEDDensity_ |] calculates a function to implement into the code using the height and LED density of the L |
|---------|---|--|
| In[3]:= | DelayTime[5000, 60] | |
| | n^{th} LED time of 1st flash = 102.041 (9.89949 | - Re[$\sqrt{98 0.326667 n}$]) milliseconds |
| | $n^{\mbox{th}}$ LED time of 2nd flash = 1010.15 + 58.3212 | $2\sqrt{300 - n}$ milliseconds |
| | | |
| | n^{th} LED delay time = -102.041 Re[$\sqrt{98 0.32}$ | 6667 n] + 102.041 Re[\(98.3267 - 0.326667 n] milliseconds) |
| | Minimum delay time (bottom of trajectory) = | 1.68 milliseconds |
| | Maximum delay time (top of trajectory) = 58 | .3 milliseconds |
| | | |
| | Flash Time | Delay Time |
| | Flash time Tf (ms) | Delay time (ms) |
| | 2000 | 60 |
| Out[3]= | 1500 | 40 |
| | 1000 Tf2 | 30 |
| | 500 | 20 |
| | 0 LED n | 0 LED n |

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

#include <math.h

define LED_PIN

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

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();



| <pre>Pixel strip(LED_COUNT, LED_PIN, NEO_GRB + NEO_KHZ800);</pre> | |
|---|--|
| n(); rightness(255); (); // initialize all pixels to off | |
| <pre>= 0; n < LED_COUNT; n++) { ait = (102.49*(4.427-sqrt((19.6-0.32*n)))); tPixelColor(n, 0, 255, 0); ow(); it); ear();</pre> | |

Serial Monitor

2. Design in TinkerCAD



thermal units and generate code



6. Convert data back to vacuum 5. Run thermal simulation in ANSYS

Create and analyze the parts of the vacuum system.

7. Plot pressure distribution

Variables

The pressure profile was characterized with variations in pump size, pump spacing, and orifice size. It was found that a system with smaller orifice holes and more ion pumps will have a lower pressure profile.

Results







Middle mirror box's orifice



Ion Pumps, Photo: Ideal Vacuum Products. Ion pump quantity, placement, and speed effect the vacuum.

3. Create program in Arduino IDE



5. Run the Circuit

Results

A 5m section of the system completed, software programs for the different science modes in progress, power requirements calculated, and recommendations on how to scale up to 100m.

Future

Scale the system up to 100m by connecting 20 5m LED strips, power injection every 10m, include all LEDs in the code, complete software for all science modes, and ensure the system meets safety specifications.

| - | - | | |
|---|---|------|--|

4. Connect Arduino to LED strip

-Program the circuit -Connect the circuit -Test the circuit on actual Arduino and LED strip

Initial design: 4 ion pumps, Final design: reduced orifice hole 0.8" orifice holes diameter to remove an ion pump



Blue-initial, orange-final. Final design meets experimental requirements at 8.67E-11 torr







// 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()

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Fermi National Accelerator Laboratory



