Electromagnetic Actuation of the James Webb Space Telescope (JWST) Microshutters

Alyssa A. Rzeszutko, 2003 NASA Academy Research Associate, Code 543

George Voellmer, Principal Investigator, Code 543

Introduction

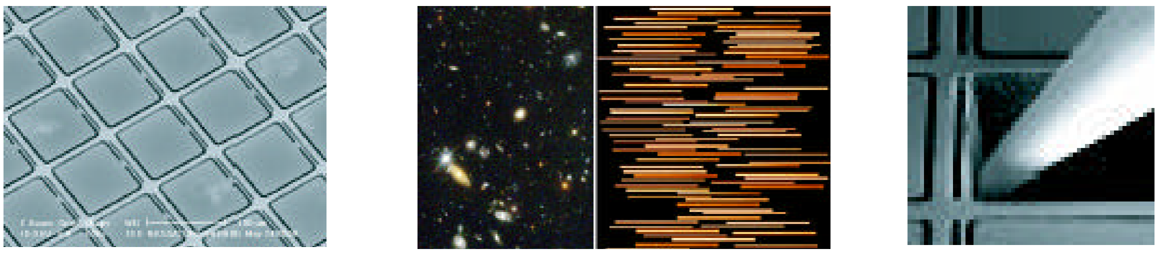
The James Webb Space Telescope, formerly known as the Next Generation Space Telescope, will depart for an L2 orbit in August 2010 upon an Ariane 5 launch vehicle. JWST will succeed the Hubble Space Telescope to look further into space than ever attempted before. Throughout the duration of the mission, proposed to last between five to ten years, the origins and composition of the universe will be studied to gain information on the formation of galaxies and stellar evolution. Scientists hope to unveil some of the mysteries of dark matter as well as the size of the universe. [1] [2]

JWST will travel approximately three months before it reaches its orbit where the instruments must endure temperatures of 30 K or lower. This telescope will carry three instruments on board. The Near Infra-Red Camera (NIRCam) and the Mid Infra-Red Instrument (MIRI) are two of the instruments. The third, the Near Infra-Red Spectrograph (NIRSpec), will observe spectra between 0.6 μm to 5 μm wavelength. NIRSpec will be able to obtain spectra from over 100 sources simultaneously [1]. This instrument employs an advanced technology, called microshutters proposed by Harvey Moseley, a scientist at NASA Goddard Space Flight Center. These shutters will be utilized when observing primordial galaxies and other stellar objects. When the telescope faces deep space regions populated with spectral sources these shutters have the unique capability of blocking overlapping spectra to easily distinguish and match each spectra to its corresponding source.

Microshutters

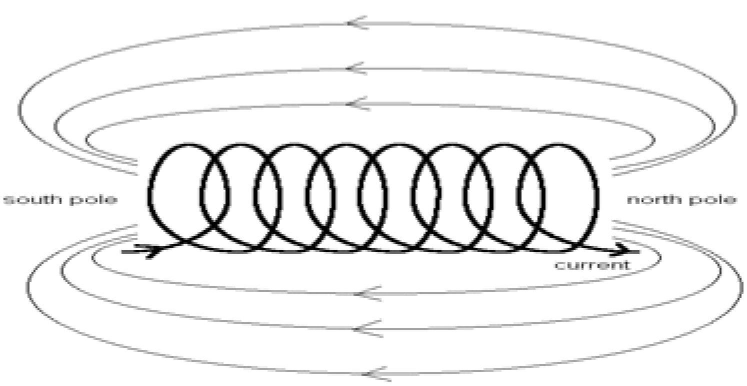
Microshutters are programmable masks, much like an aperture mask on a regular telescope, however they open under a magnetic field. Each shutter is 100 x 200 μm, and each array consists of 2000 x 1000 individual shutters. The shutter is a silicon nitride blade with cobalt iron deposited on top for magnetization. It is suspended on a torsion beam that can rotate 90 degrees out of the plane of the array. The shutters sit in a grid pattern each surrounded by walls through which voltage runs.

Magnetic actuation causes all of the shutters to rotate open at once. When open, the microshutters must be latched into place; 90° out of the array plane, and remain in that position until spectral observation is desired. Each wall row and each wall column has a live voltage line to connect to all of the shutters. A magnetic field is created by the potential difference between the shutter and the vertical wall causing the shutters to latch. The shutter has +40 Volts where the vertical electrode has -40 Volts. Both the rows and columns voltage are superimposed causing the microshutters to have a total of 80 Volts on the surrounding walls. Only 40 Volts are needed to keep the shutter in position. To address an individual shutter to return to its closed position, the voltage is turned off in the column and row in which the shutter lies. The shutter desired to close now has 0 Volts. The other shutters in its row and column will remain open because they still have 40 Volts applied to them.



[3]

The current design to actuate the microshutters consists of a mechanical arm that holds a magnet and sweeps the span of the array opening shutters row-by-row. The design has many complications that consist of moving components and many mechanisms to operate the mechanical arm. The designs complexity hampers its reliability. The James Webb Space Telescope will be placed in an L2 orbit, making a maintenance mission improbable for humans to reach should any component fail. Also, the magnet is only large and strong enough to actuate a single row at each position along the mechanical arm's sweeping path, taking time to open all of the shutters. A proposal for a simpler, more effective design was implemented and is undergoing testing. Current flowing through coiled wire generates a magnetic field within the coil. This fact is being used in the design of an electromagnet, or solenoid, that will actuate all of the microshutters at once.



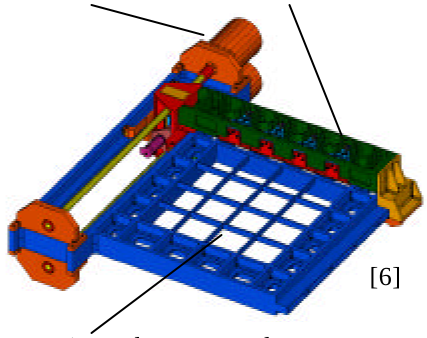
Simple diagram of an electromagnet

Field lines are uniform and parallel in the center of the magnet

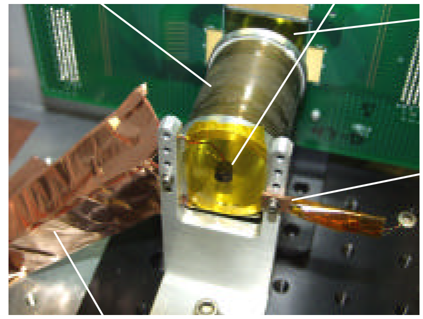
[4] [5]

Both the current design and the proposed design are shown below:

Current Flight Design



Proposed Design



A summary of the advantages and the disadvantages of each design are stated in the chart below:

Mobile Arm Design		Electromagnetic Design	
Moving Components		No Moving Parts	
Many Mechanisms		No Mechanisms	
Highly Complex Design		Simple Design	
Row-by-Row Actuation		Simultaneous Actuation	
Low Power		High Power	

Advantages	
Disadvantages	

The super-conducting magnet used in initial tests had Niobium Titanium wire which can only operate below 7 K. The magnet had 4000 turns. The dimensions are as follows:

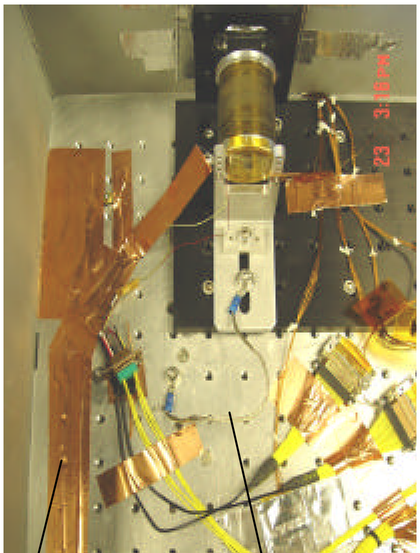
~33.0 mm inner diameter

~40.5 mm outer diameter

~47.5 mm length

Electromagnetic Actuation

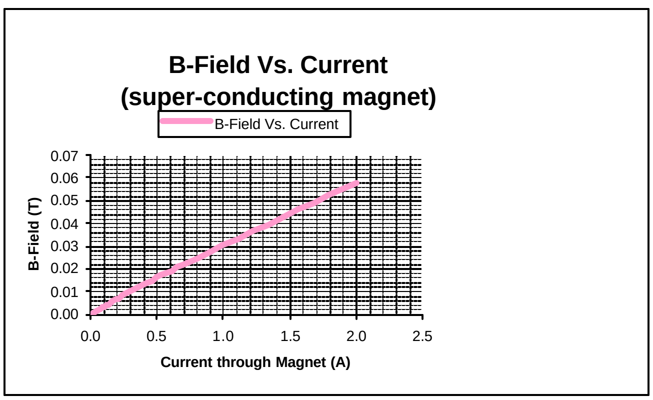
The first test failed to actuate any shutters. Because the temperature varied around 7 K, the magnet could not reach a stable, super-conductive state. The niobium titanium wires have too much resistance to allow current to flow causing excessive heating within the magnet when above 7 K. Adjustments were made between the first and second tests. Copper heat straps were connected from the cold plate to the wiring joints offering better thermal conduction. Indium was placed underneath the heat sinks. Indium is an excellent thermal conductor and is also malleable. All loose wires were secured to the cold plate with copper tape. Finally spring washers were placed under the magnet mounting screws to maintain preload. Higher pressure between the magnet and its bracket creates a better thermal interface.



Copper Tape Heat Strap

Heat straps

Initial Test Results



NOTE: 0.2 T is needed to open most or all of the microshutters
B-Field is measured with a Hall Probe

When 2 Amps was applied to the system, a magnetic field of 0.058 T was obtained. This weak field did open a few shutters in the array; however, 0.2 T is needed to actuate all of the shutters.

Improvements to the dewar are underway in preparation for the next set of tests. The cryogenic harness that connects the liquid nitrogen tank (77 K), the liquid helium tank (4 K), and the cold plate on which the equipment is attached has been replaced. The manganin wire has been removed and copper wire has been routed through the dewar to offer good thermal conductance. Copper's low resistance causes heat to dissipate easily. By Stycasting (permanently securing) the wires to the sides of each tank and wrapping them around the vapor vent to further cool them allows for most of the heat generated by the current flow and the wire resistance to be dumped into the cryogenic tanks before reaching the super-conducting magnet. Further improvements included replacing the first super-conducting magnet. One wire broke after the second test due to its extensive use in previous research groups. A new, 8000 turn, niobium titanium magnet was obtained, which has twice the amount of turns than the previous magnet. The number of turns is directly proportional to the magnetic field generated. With the same current flowing through the magnet, but increasing the amount of turns, the magnetic field is expected to also increase. A simplified equation of the one used in the calculation of the magnetic field measured by the Hall probe is reported below:

$$B = m_0 n I$$

$$B = magnetic\ field$$
$$m_0 = permeability\ of\ free\ space$$
$$n = \frac{N}{L} = \#\ of\ turns\ per\ unit\ length$$
$$I = current$$

This magnet also has copper cladding over the niobium titanium wire to keep the magnet super-conductive when secured to the cold plate. Finally, a more thermally insulated window on the dewar wall would be advantageous to future experiments. A camera and a bright lamp are placed against the window that offers a transparent view of the microshutters. When turned on, the lamp produces a tremendous amount of heat that transfers inside of the dewar causing instability to the super-conductivity of the magnet.

Work in Progress

Before August 8th, 2003, the original test will be repeated with a higher quality and more powerful niobium titanium electromagnet. During testing, the high magnification/high resolution digital camera will be used to observe smaller sections of the array, specifically 10 x 20 shutters. By focusing on small portions of the array, the angle at which the shutters open will be identified. By further adjusting the magnet's characteristics such as the number of turns, the wire gage, the coil diameter, or the coil length, the desired magnetic field to actuate the shutters can be obtained. Currently, 0.2 T is needed to actuate all of the shutters.

In hopes that the previously mentioned goals are achieved, further design, testing and analysis should be implemented. The Microshutter Fabrication Team is in need of a copper electromagnet that operates at room temperature for life testing of the shutters.

Should the super-conductive and copper electromagnets actuate the shutters during testing, the Flight Design of the magnet should commence. This magnet must operate at 30 K, which will cause alterations to the wires used in previous experiments. For every magnet tested, ANSYS, a computational simulation program will be used to predict the theoretical outcome of the magnet to compare to experimental data.

References

[1] http://www.stsci.edu/jwst/

[2] http://ngst.gsfc.nasa.gov/htm

[3] A. S. Kutyrev, S. H. Moseley, "Programmable 2D Addressable Cryogenic Aperture Masks"

[4] Tipler, P. A. (1999) Physics for Scientists and Engineers, 4th ed., Vol. 2, New York, New York

[5] http://www. physics.gla.ac.uk/~kskeldon/PubSci/exhibits/E2/

[6] S. H. Moseley (Feb 2003) "Microshutter Array (MSA) Technical Status Report"

[7] http://www. tpub.com/neets/book4/11e.htm

Acknowledgements

- Illinois Space Grant Consortium
- Ernest Buchanan, Code 680
- Dr. Todd King, Code 541
- Dr. Alexander Kutyrev, Code 685
- James Loughlin, Code 542
- David Rapchun, Code 685
- Scott Schwinger, Code 544
- Dr. Peter Shirron, Code 552
- George Voellmer, Code 543