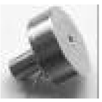
A New Miniature Pulsed Supersonic Molecular Beam Source



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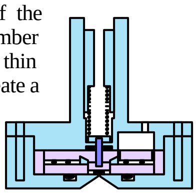
Aim: To build a smaller, faster, simpler and more reliable pulsed supersonic molecular beam source for spectroscopic, gas-surface scattering and molecular beam experiments.

Introduction:

Pulsed supersonic molecular beam sources offer many important features: **high beam intensity, low gas loads, supersonic cooling and easy matching with pulsed lasers and data acquisition systems**. Currently used pulsed molecular beam sources are complicated in design, large in size, and expensive. The pulsed valve in this presentation not only has very short pulses (about 100 µs FWHM), but is also very compact (20 mm diameter, 18 mm length), corrosion resistant and can be easily mounted in experimental chambers with various geometry. In addition, it is reliable, simple in design and with a small number of parts. The prototype pulsed valve above consists of a lower stainless steel body with a 350 µm diameter orifice, a plunger with a viton tip, a coil and an upper stainless steel body with a spring.

Design considerations:



The schematic diagram of the valve is shown on the right. The magnetic flux of the coil is determined by the number of turns per meter, hence a thin planar coil can be used to create a large magnetic flux on a thin element (the plunger). A closed magnetic circuit design using Vanadium Permandur (50% Fe, 48% Co and 2% V) concentrates the magnetic flux density and enables us to reach the saturation limit of 2.4 T on the plunger. This flux is achieved with a relatively small 20-40 amp current pulse supplied by discharging a 10 µF capacitor charged to 100-250 V. Extensive modelling of the valve was performed using FEMM 3.1, a "Finite Element Magnetic Modelling" suite of programs for solving static and low frequency 2D or axisymmetric problems. For Magnetostatic problems the relevant Maxwell's equations relating the field intensity H, flux density B, current density J and (non-linear) permeability µ are:

$$\nabla \times H = J \qquad \nabla \cdot B = 0 \qquad B = \mu(B)\,H$$

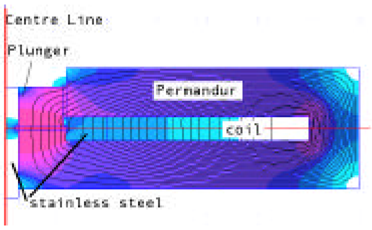
FEMM finds a field which satisfies these equations via a Magnetic Vector Potential, A, such that

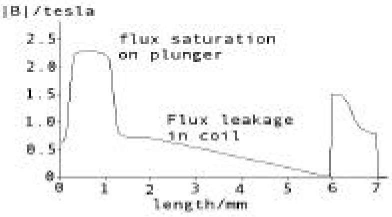
$$B = \nabla \times A \qquad \nabla \times [\nabla(1/\mu(B)) \times A] = J$$

Force calculations are performed using Maxwell's Stress Tensor that describes the force per unit area produced by a magnetic field on a surface. The differential force is

$$dF = 0.5\,(H(B{*}n)+B(H{*}n)-(H{*}B)n)$$

where n is the direction normal to the surface. The net force is found by integrating over a surface enclosing the object. The axisymmetric solution below has 10,327 nodes and 20,474 elements. The 48 turn coil, 0.5 mm thick and carrying 25 amps, generates a maximum force of 7.9 N on the plunger. The plunger mass of ~ 5 x 10^{-5} kg yields an acceleration of around 13,500 **g** and a predicted time to travel 0.1 mm of 35 µs. In reality the current pulse only holds its peak value for a short time, and the presence of spring has two negative effects. It opposes the magnetic force during opening and increase the moving mass of the system producing a measured time of around 100-160 µs. The simulated magnetic field and its magnitude of flux density, B, along the horizontal red line are also shown below:





Experiments:

To measure the gas pulse profile, the valve is attached to a test chamber with a typical base pressure of approx. 10^{-6} mbars. A naked Bayard-Alpert gauge is used to measure the gas pulse. The collector output is fed into a fast current amplifier which is connected to a digital oscilloscope. The pulsed valve is driven by a simple custom-built thyristor controlled capacitor discharge unit.

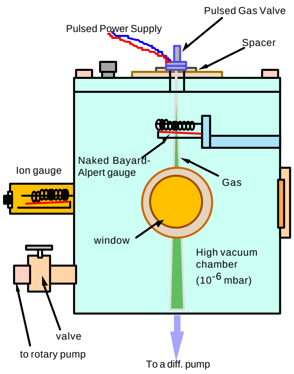
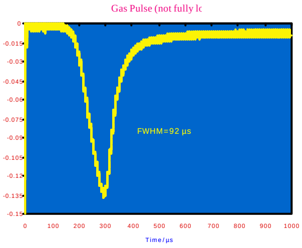


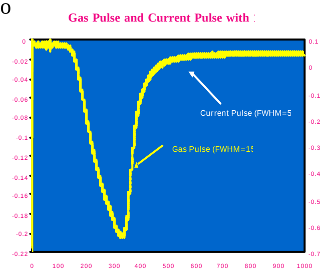
Diagram of a Testing Chamber and Valve

Results:

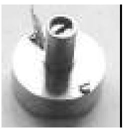
A typical partially choked gas pulse at 1 atm. air recorded with the fast ionisation gauge is shown below. The discharge capacitor is 15.8 µF at about 150 V. The measured FWHM for gas pulses was 92 µs. The max. current pulse is 20 A with about 77 µs width (FWHM). Because of the low current in the coil, the pulsed valve generates little heat.


Gas Pulse (not fully lc

The low-right figure shows the fully loaded gas pulse(the valve is fully opened), the width of the pulse increased to 154 µs (FWHM). The gas pulse shape has also been changed. Initially, the gas pulse increases quickly, but starts to decelerate when the current pulse finishes (the current pulse shape is in white). However, the valve closing time is the same, since it depends only on its spring.


Gas Pulse and Current Pulse with

Future work:



A more efficient magnetic design can be achieved by increasing the coil height to 0.75mm to minimise flux leakage across the coil. Optimisation of the current pulse is required to match the mechanical time response. Fabrication of small multiturn planar coils using UV LIGA and electrodeposition techniques will produce an even smaller valve. Problems of heating due to eddy currents at high repetition rates need to be addressed. An improved nozzle sealing design with a finite plunger displacement before opening should produce pulse widths of 30-50 µs. Finally we are modelling a novel design for a springless valve which uses multiple coils to provide variable path magnetic circuits.

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Web site: http://mch3w.ch.man.ac.uk/phys/MolecularBeam/Beamgroup.html