Development of a Low-Cost, Miniature Mass Spectrometer

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ABSTRACT

There exists a need to monitor several gases simultaneously in a wide variety of environments. These applications require several chemical detectors or a single monitor that can detect all the species of interest. Mass spectrometers are such universal detectors, but they have traditionally been a high cost, large platform solution. Our goal is to use new design and manufacturing technology to reduce the cost and size of MS solutions such that the units become portable and disposable. We rely on experience and computer modeling (Simion, Ansys) to generate viable designs and then prototype and test worthy candidates on the laboratory bench. Three criteria for pursuing any design are 1) acceptable performance for market application, 2) manufacturability, and 3) an appropriate communications interface.

We have built a 200 amu unit based on a design pioneered by Diaz, Gentry, and Giese and licensed from the University of Minnesota.[1, 2] Our first commercial protoype, an 80 amu unit is due for test in mid-April. Our goal for both of these units is to reduce the cost of the core package (source, analyzer, and detector) to around $500. This target would make the units disposable or recyclable and thus eliminate troubleshooting in favor of replacement. We plan to achieve this using currently available mass production technology (e.g., lithography).

Our plans for communications are based on a platform independent, open information architecture allowing a user to communicate with the sensor from anywhere at any time. An embedded controller will run the instrument and deliver data over any internet-based infrastructure, wired or wireless, with a browser-based user interface. The internet access will employ a TCP/IP/Ethernet protocol which is fast becoming a standard for information management. In addition the controller will also support an RS232/485 mode for handling industry specific protocols (e.g., FieldBus, ModBus, DevNet). Thus, a user with internet access will be able to communicate with a network of remotely deployed sensors from anywhere at any time.

DISCUSSION

Our benchmark 200 amu unit is shown in Figure 1 and is essentially the same as the University of Minnesota compact double focusing mass spectrometer (CDFMS). The device has a 2 cm radius and is made using conventional machining techniques. The path length for a central trajectory is 4.5 cm. This unit is being tested in our laboratory to assess its performance and lifetime. For example, Figure 2 shows B-field measurements when the NdFeB magnets are shielded by different types of stainless steel. This version is intended to provide a benchmark for future units.

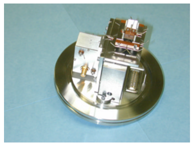

Figure 1 Large unit on ISO100

One thrust of our current research is to translate this design into a unit that can be manufactured more easily. We have divided this into four areas: source, analyzer, detector, and support flange. We are pursuing a plug-in source that would work on all platforms, an analyzer design that can be produced using lithographic techniques, a miniaturized electron multiplier for a detector, and a variety of vacuum feedthrough technologies.

We are interested in moving away from conventional materials (e.g., machined stainless steel) and exploring the opportunities afforded by ceramics and plastics. The latter are particularly intriguing as the short path length reduces pumping requirements and makes outgassing less of a problem.

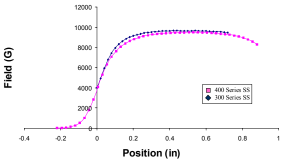

Figure 2 B-field data

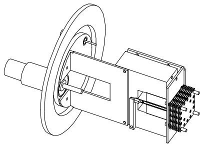

Figure 3 Small unit on KF50

A drawing of a commercial unit we plan to deliver is shown in Figure 3. It has an 8 mm radius and a path length along the central trajectory of about 2 cm. Again the design is divided into four parts. The source is made from modified commercially available parts (Kimball Physics). The analyzer and detector are similar to those of the the larger unit. This protoype will feature a DB15 feedthrough (Ceramaseal) for control voltages, an SMB connector for signal, and an MHV feedthrough for high voltage. This prototype is currently being built using conventional machining methods.

We use modeling to decide which designs are worth pursuing. Figure 4 shows a SIMION model of this small unit with ion trajectories (Blue = 3 amu, Red = 4 amu, and Green = 5 amu). We have also modeled various source designs and tried to model magnetic field effects by patching in B fields to simulate the measured values (e.g., the residual field in the source region). In addition, we have carried out some magnetic modeling of the small prototype using FEA and boundary-value software. At present, these calculations have not uncovered many surprises but have demonstrated that they provide a reasonable model of the B field and we expect they will play a much larger role when we explore designs that use minimal magnetic material and specially shaped yokes.

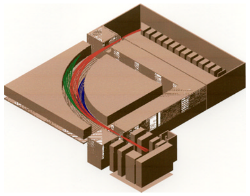

Figure 4 SIMION model of small unit

While we are just underway, we have taken a few spectra that have allowed us to refine our electronic control and learn about the operating parameters of the large instrument that require strict control and those that are more forgiving. We are currently moving ahead with a prototype control board, both for the laboratory benchtop and for portable demonstration, that features small, modular power supplies (EMCO). The current user interface is through LabView 6i (National Instruments) and connects to the board via a desktop PC with standard PCI cards. We have also run the large unit using PCMCIA cards, LabView 6i, and a laptop computer. The spectra shown in Figure 5 were taken using the larger unit. The methane spectrum has acceptable resolution and relative intensity. The octane spectrum was taken at 4×10^{-6} Torr and displays several obvious problems. We are refining both our electronics and source geometry to fix these anomalies.

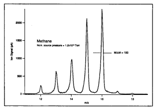

Figure 5 Spectrum of methane

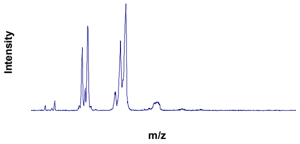

Figure 6 Spectrum of octane

The goals for communication architecture are shown in Figure 7. The objective is to connect to the sensor by several means (e.g., ModBus, DeviceNet, serial communication). Fundamentally, the sensor is run by an embedded controller that can be accessed by standard industry buses, intranets, internet, and handheld wireless devices. This architecture eliminates the need to provide separately engineered solutions for each style of interface. The Web server feature allows communication to the instrument using HTML pages.

One of the concepts we are pioneering is called CyberSpec^{TM}. The idea is to have a distributed network of mass sensors that are accessible through the internet. Communication can be either wired or wireless as shown in Figure 8. Thus, users can retrieve the data from a network of sensors anytime, anywhere as long as they have a device which can access the internet. This will allow desktop or PDA monitoring of real time harsh environment data that is being collected anywhere in the world.

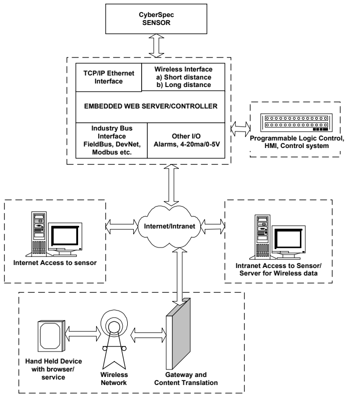

Figure 7 Communication architecture

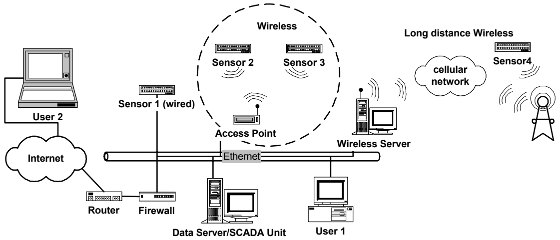

Figure 8 Cyberspec scheme

SUMMARY

The goal of Mass Sensors, Inc. is to provide low-cost, miniature mass spectrometers for universal gas detection. To that end we have begun to build prototypes based on relatively new technology with an eye toward high-volume manufacturability. We plan to control these devices using internet-based technology that will make these disposable sensors accessible from anywhere at any time to anyone with any type of internet access.

ACKNOWLEDGMENTS

The authors acknowledge the advice and support of Jay Ray of De Tech in all matters relating to multipliers, Tim Dorsey of MA Tech for the use of his vacuum equipment, Dr. David Bomse of Southwest Sciences for hardware and software advice and support, and Prof. Michael Gross of Washington University NIH MS Resource for supplying samples.

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