

Major Constituent Analyzer (MCA) Mass Spectrometer Operating Life Improvements

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ABSTRACT

The Major Constituent Analyzer (MCA) is a mass spectrometer system that measures the major constituents of the International Space Station (ISS) atmosphere. Experience has indicated that the operating life of the mass spectrometer is limited by the operating life of the ion pump, which maintains mass spectrometer vacuum. This paper summarizes the use of trend data from on orbit operations and ground testing to identify and understand the factors affecting ion pump life and to predict ion pump life on orbit. In addition, potential improvements currently under consideration to increase ion pump life, and therefore mass spectrometer life, are discussed.

INTRODUCTION

The MCA is located in the Atmosphere Revitalization (AR) Rack in the U. S. Laboratory. It is the primary tool for ensuring that concentrations of oxygen and carbon dioxide aboard ISS are maintained within safe limits. Also, since it measures the partial pressure of nitrogen directly, it provides ground based flight controllers with the capability to determine cabin air leakage to space by observing the rate of decay of nitrogen partial pressure.

The MCA consists of seven On-orbit Replaceable Units (ORUs) mounted in a drawer-type chassis. These are shown in Figure 1. ORU 2 (also referred to as the Major Constituent Analyzer Assembly in Figure 1) contains the mass spectrometer, the ion pump, and the electronics that control operation of these components and condition mass spectrometer signal outputs. The MCA operates continuously on orbit and is powered down only for maintenance of its ORUs or other systems in the U.S. Lab AR Rack, or, in the event of a failure or anomaly requiring power down. ORU 2 has the most limited operating life of all the MCA ORUs due to consumables within the pump and unforeseen aging characteristics on-orbit. When an ion pump reaches the end of its operating life, the entire ORU 2 must be replaced. Improving the length and predictability of the ion pump operating life offers the potential for significant savings in hardware launch, replacement and refurbishment costs as well as for improved operations planning and utilization of crew time. Considerable attention has therefore been paid to understanding the

factors that affect ion pump operating life and enabling its improved prediction.

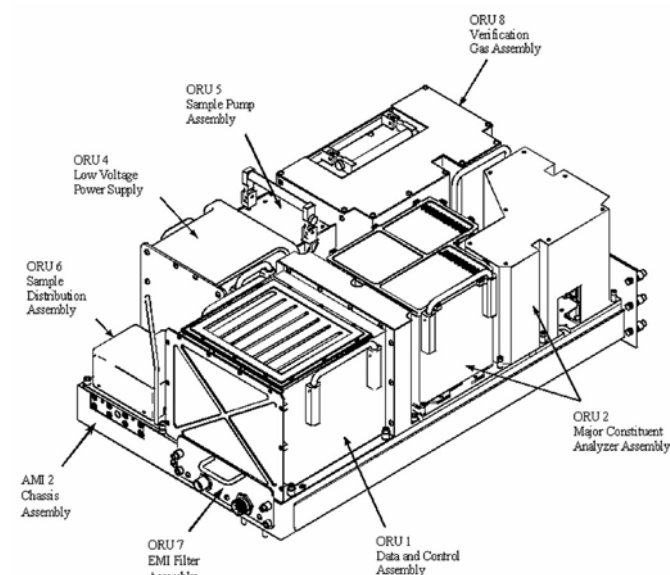


Figure 1 - Major Constituent Analyzer

This paper will review trend data related to ion pump operating life obtained from on orbit experience and will summarize findings to date. This information will be organized as follows. The MCA OPERATION section will present an overview of MCA and ion pump operation. The ION PUMP TREND DATA section will define those parameters believed to affect ion pump life and will discuss each of these with reference to trend data from on-orbit operation. The CONCLUSIONS section will summarize findings to date and will identify potential changes currently under consideration to increase ion pump operating life. A summary of overall MCA operating experience is contained in Reference (1).

MCA OPERATION

Figure 2 is a schematic representation of the MCA. The red line in this figure shows the sample air flow path through the MCA during operation. One of two redundant sample pumps in the Series Sample Pump

Assembly (ORU 5) draws air from various ISS modules through the Sample Distribution Assembly (ORU 6) in the MCA and past the Mass Spectrometer (ORU 2) inlet. The major portion of the sample airflow flows past the Mass Spectrometer inlet, through the Verification Gas Assembly (ORU 8), and into the Series Sample Pump Assembly. From there, the sample air flow is pumped back through ORU 8, from which it exits to the interior of the Atmosphere Revitalization (AR) Rack. A very small portion of the sample gas flow is drawn into the mass spectrometer, which is maintained at vacuum by the ion pump. The data is telemetered to the ground every 10 seconds.

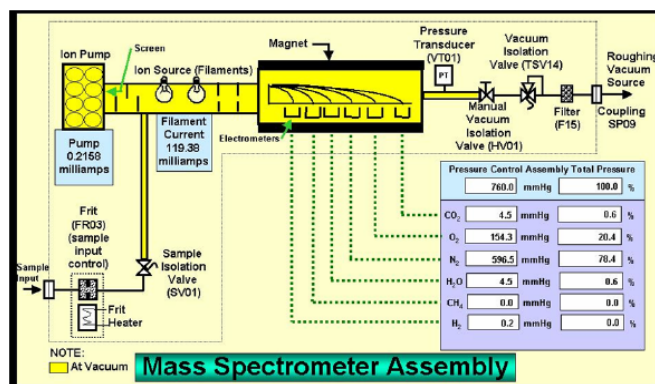


Figure 3 – ORU 2 Schematic

ION PUMP OPERATION

Unlike turbo pumps, which are dependent on high speed rotating parts, and diffusion pumps, which are dependent on gravity, ion pumps operate with no moving parts, are orientation independent, and consume very little power. The specific pump used in the MCA is a 4 liter per second 'noble-diode' pump that weighs approximately 3 pounds and consumes approximately 10 milliwatts of power in normal operation.

Sputter ion pumps work with two principal mechanisms: gettering and sputtering. Gettering removes the reactive components of air (nitrogen, oxygen, water, hydrocarbons, etc.), and sputtering removes the non-reactive components (noble gases, primarily argon). In operation, gas molecules entering the pump are ionized in a volume between two cathode plates, one titanium, and the other tantalum. The resulting ions are accelerated vigorously toward whichever happens to be the nearest plate under a high voltage bias, striking the plate with sufficient force to sputter a cathode atom (Ti or Ta) off the plate. In this way, a film of fresh new metal is continuously deposited on surfaces internal to the pump.

This fresh metal is very reactive to air, 'gettering' air molecules to form titanium and tantalum oxides, nitrides, and various non-volatile salts. Thus, any material that goes into the pump becomes irreversibly part of the pump's interior. Sputtering new titanium and tantalum from the cathodes is important because any exposed metal is soon passivated with a layer of oxides, which is why these metals don't spontaneously decompose in air.

Argon is sufficiently non-reactive to either fresh titanium or tantalum to require a separate mechanism, and the tantalum cathode is used in 'noble diode' pumps primarily because it does this better than the titanium cathode. A fraction of the gas that enters the pump will be found on the walls of the pump. A fraction of those wall-associated molecules are buried when sputtered Ti or Ta atoms are deposited on the walls. If the sample input rate for noble gases is sufficiently low (argon on ISS is less than 1%), and if the sputter rate is sufficiently

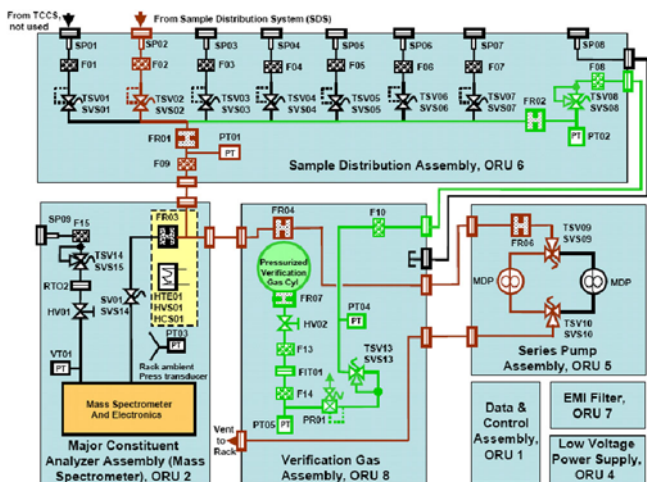


Figure 2 - MCA Schematic

MASS SPECTROMETER OPERATION

Figure 3 is a schematic representation of ORU 2, which shows the mass spectrometer and ion pump. Sample gas drawn into the mass spectrometer passes through a flow restrictor frit (lower left of Figure 3) and enters the ion source and the ion pump. Gas molecules are ionized by collisions with electrons in the ion source. The positively charged ions are focused, accelerated and separated by electric and magnetic fields. The six gases measured by the MCA (nitrogen, oxygen, carbon dioxide, water vapor, hydrogen and methane) are collected on six electrometers. Electrometer signals are then converted into partial pressure values for each of the six constituents.

The specific type of spectrometer used, a magnetic sector spectrometer, operates internally at 10^{-5} torr or better, allowing the different constituent ions a clear path to their separate electrometers. The vacuum pump used to maintain this vacuum is a sputter ion pump, commonly used in low-power, high-reliability systems for their simplicity and efficiency.

high, the removal rate exceeds the input rate and vacuum is maintained. Pumping by this mechanism is two to three orders of magnitude less efficient than the gettering mechanism.

As increasing amounts of cathode material is eroded over time, surface irregularities (or scale) may build up on the cathode and anode. Occasionally, this scale buildup results in large transient ion pump current spikes, which in turn may release transient bursts of nitrogen gas from the cathode material deposited on the ion pump walls. Small quantities of other gases may be released, also, but since nitrogen is by far the most abundant gas, and is the least well bonded to the cathode material, it is the only constituent released in significant quantities. If such a transient release of nitrogen occurs during that portion of the MCA calibration process when background values of the various gases are being measured (called a Zero Calibration), the MCA firmware may store an erroneous background value for nitrogen. This will cause errors in the measurement of all the atmosphere gas constituents read by the MCA. As a result, procedural constraints have been implemented to detect invalid Zero Calibrations and repeat them to ensure valid nitrogen background levels.

ION PUMP TREND DATA

ION PUMP OPERATING LIFE EXPERIENCE

Once activated, the MCA operates continuously, with the exception of brief periods of down time to permit equipment maintenance. Hence the ORU 2 and its ion pump accumulate considerable operating time. To date, a total of four ORU 2s have been used on orbit. These ORUs and the dates they were installed in and removed from the U. S. Lab MCA are shown in Table 1. One of these ORU 2s, serial number F0001, is currently undergoing its second usage on orbit. To date, this ORU 02 has been in continuous operation for over two years.

operating life are based on trend data from on orbit operation of the last three ORU 2s shown in Table 1 (serial numbers F0003, F0002 and F0001 during its second usage on orbit).

FACTORS AFFECTING ION PUMP OPERATING LIFE

Cathode material is eroded as a normal part of ion pump operation. The cathode material cannot be observed directly during operation; however, there are a number of parameters that appear to serve as good indicators of cathode wear and therefore merit attention as potential indicators of ion pump life. Since cathode erosion is a result of the acceleration of ionized gases into the cathode, it would seem that the rate of erosion would be primarily affected by ion pump current and that total erosion would be indicated by ion pump current times operating time (amp-hours). In addition, as cathode erosion progresses over operating time and scale builds up, the probability of large transient ion pump current spikes increases as does the probability of invalid Zero Calibrations. On-orbit data for the following parameters have been trended over time to determine whether they can provide insight into ion pump and ORU 2 operating life.

- Ion Pump Amp-hours
- Ion Pump Current Profile (Current vs. Operating Time)
- Magnitude and Frequency of Ion Pump Current Spikes
- Frequency of Bad Zero Calibrations

Results of this trending are discussed below.

Ion Pump Amp-Hours

Ion pump amp-hours have been calculated and plotted versus operating time for each of the three ORU 2s that have accumulated significant time on orbit. This plot is shown in Figure 4.

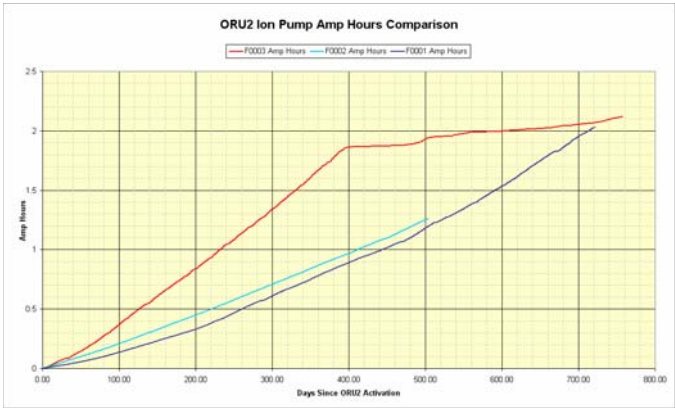


Figure 4 – Ion Pump Amp-Hours

The first two ORU 2s (serial numbers F0001 during its first usage on orbit and F0004) did not accumulate sufficient ion pump operating time to be included in this report. Data, discussions and conclusions regarding

ORU 2 serial number F0003 accumulated ion pump amp-hours at the highest rate. This ORU 2 may have