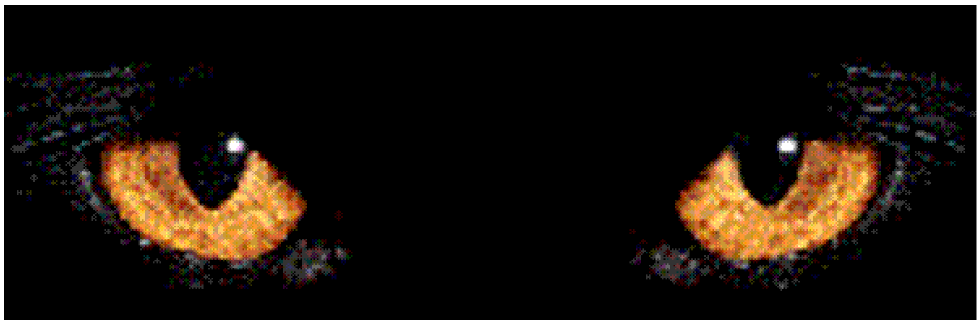
PROCESS CHAMBER ASSURANCE TOOL

DEDICATED TO IMPROVING PROCESS PERFORMANCE



DESIGNED TO TEST MASS FLOW CONTROLLERS, PRESSURE SENSORS, PUMP PERFORMANCE AND CHAMBER INTEGRITY, THE CAT IS USED PRIMARILY FOR:

- ***PERFORMANCE MONITORING OF PROCESS TOOL COMPONENTS TO PREVENT UNSCHEDULED DOWN TIME AND MAINTENANCE***
- ***FINGERPRINTING OF HIGH YIELD PROCESS TOOLS FOR SYSTEM MATCHING WITH LIKE TOOLS***
- ***BRINGING NEW AND DOWN SYSTEMS ONLINE AND IN SPECIFICATION***
- ***SETTING A BASELINE STANDARD BEFORE RUNNING A PROCESS***

IN-SITU ANALYSIS

Unlike independent, off line component testing, the CAT checks the process tool components while they are in place on the tool. Pressure sensors are tested without being removed. MFCs tested without interference, using the process gas used under normal operation. Pump performance and chamber integrity are tested with all components in place, creating a more accurate picture of performance.

INDEPENDENT AUDITOR

The key to the CAT's performance is the independent NIST traceable reference. The reference is an accurately calibrated assembly which provides the calibration components for process chamber testing. Even though most process tools have some of their own diagnostic tools and processes, the components used for testing are typically the very components being tested. Using the independent reference and applying the gas laws and NIST methodology, the CAT assures creditable results.

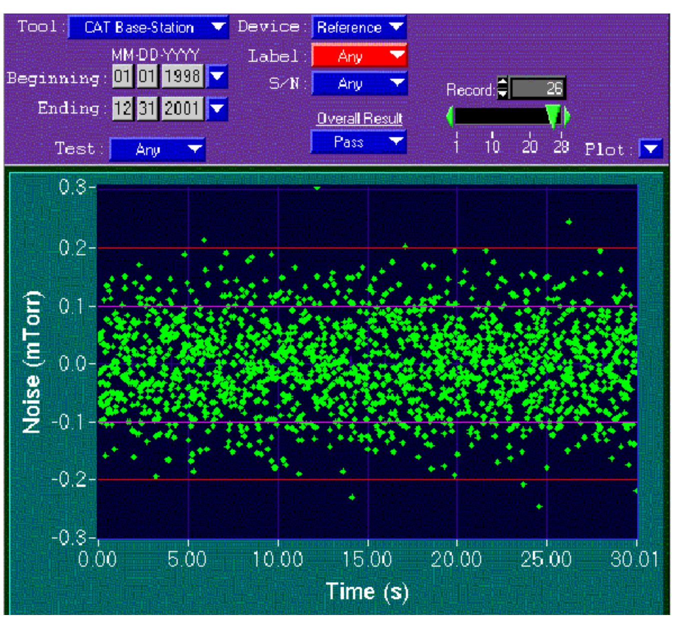
WHAT ARE THE CAT TESTS?

The CAT is designed to test the gas handling components of the process tool which include *pressure sensors, mass flow controllers, pump performance* and *chamber integrity.* The National Institute of Science and Technology (NIST) *rate of rise* methodology is used to assure accurate results. Users may select which components and which tests to run. The tests include the following.

Pressure Sensors

Zero Offset-

The CAT accurately references pressures below 10^{-5} Torr. By comparing tool and reference base pressures, with the reference attached to the process tool, the pressure sensor zero offset is established.

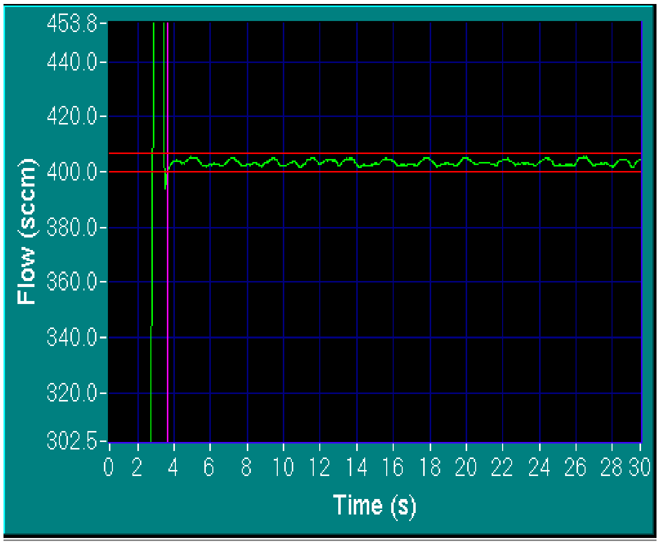


Pressure Sensor Quality-

The accuracy and linearity of the pressure sensor are tested. Users can define the pressure band for testing and evaluate the linearity deviation over the designated range.

Noise –

Both mechanical vibration and electrical interference affect the pressure sensor performance. The noise test allows the user to set control bands for acceptable noise levels and observe any degradation of performance over time.



Mass Flow Controllers

MFCs are tested on the tool, flowing process gases for true performance evaluation. Each MFC is tested for deviations in linearity, zero offset and gain. Between 1 and 10 flow rates may be defined. Tests performed at each flow rate include average flow rate, maximum flow, flow stability and time to controlled flow.

Zero offset, gain and deviation in linearity-

Based on the MFC running more than three flow rates, the testing checks the overall linearity and accuracy of the MFC performance. The user will be able to tell if the MFC is out of specification and needs to be replaced, recalibrated or calibration compensated (see CCM option). The user may define the acceptable tolerance level for their needs creating a viable pass or fail parameter.

Time to control, flow average, overshoot, flow deviation and rate of rise time-

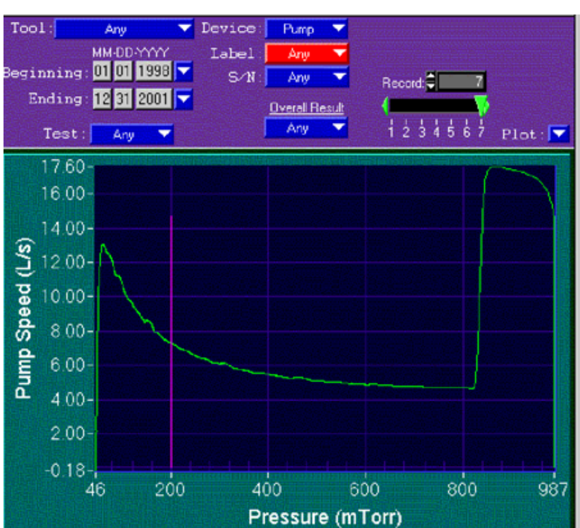
Again the user has the option to set the control parameters. The *time to control* test shows how long the MFC required from start to attaining controlled flow at the set flow rate. *Maximum flow* displays the overshoot flow rate before coming into control. *Flow stability* shows the deviations from the set flow rate after coming into control. All are factors key to maintaining process stability.

Process Chamber Tests

Effective Volume-

This test provides a value related to the internal volume of the process chamber. If the temperature of the chamber is known, an accurate value for its true volume is provided to the user. Changes in this measurement in future tests would indicate a change in temperature or changes in the actual volume.

Leak-up rate-



The CAT checks the chamber leak rate in mTorr/minute. In many cases, real and virtual leaks can be differentiated.

Pumping Stack Performance

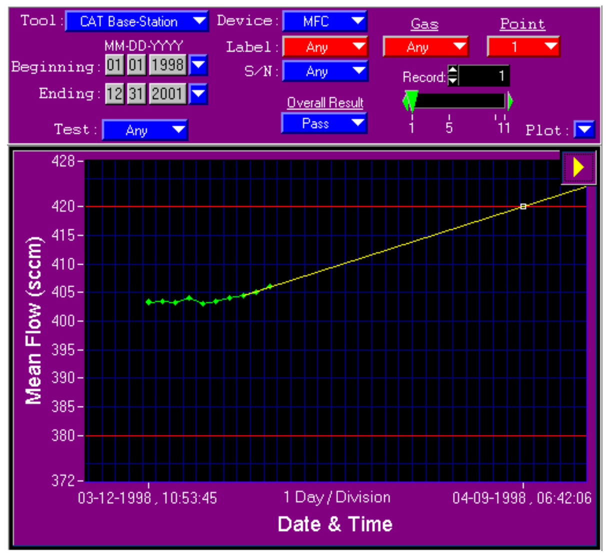
The CAT performs a sensitive measurement of pump dynamic performance and repeatability. The time required to achieve a user-defined working target pressure is measured. The pump speed at a user- defined pressure is also provided. By creating a history of test results, users can detect minor changes in performance before a critical shut down occurs, gaining considerable savings in both time and money.

Quickscan RGA (optional)

The Quickscan Residual Gas Analyzer option is capable of operating at pressures up to 15 mtorr, thus eliminating the need for differential pumping. The RGA option does a base pressure scan of the process chamber. Results are compared to both historic scan data and hard limits defined by the user.   Pass or fail results are defined for up to ten peaks.

TREND ANALYSIS

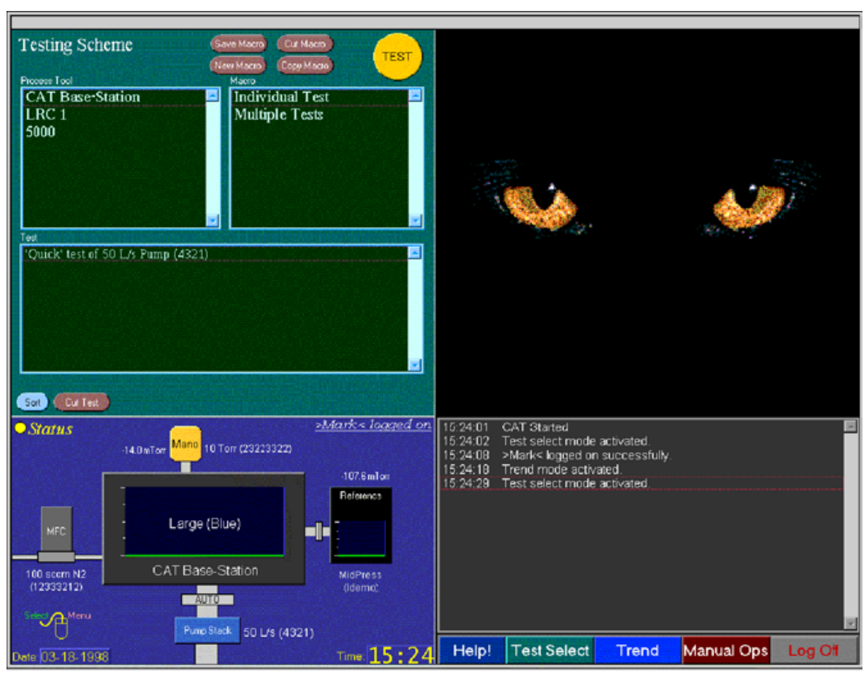
All of the test results are stored in a database for future reference. By analyzing a body of data results, trending may help predict failures on tool components such as MFCs, manometers and pumps. For example, after testing an MFC for a couple of weeks, we can see that the mean flow has started rise over the last few days. Even though the MFC is still in spec, the trend analysis predicts that the MFC will be out of spec in about three weeks.   Such trend analysis is very valuable in helping to schedule down time for repairs and for knowing what repairs are needed.



User Friendly Features

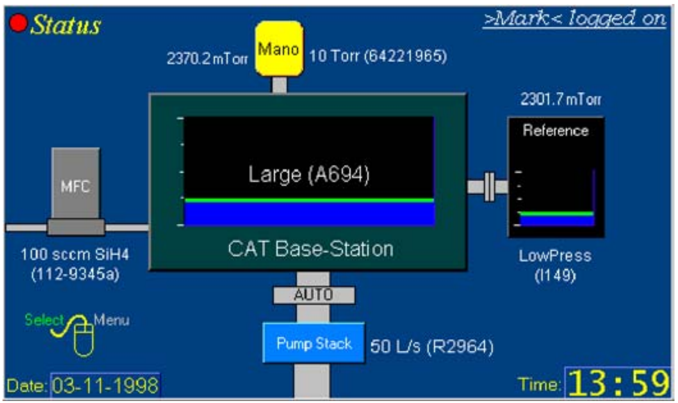
WINDOWS SOFTWARE INTERFACE

The control software operates under Windows 95 (or Windows 98). Cue cards and help screens navigate operators through the test procedures making testing a simple operation. A great deal of flexibility allows engineers to design the full array of test or focus on one area of concern.



SECURITY

The CAT software features four levels of security. Operators may run all of the configured tests. Service security level users may run tests and view configurations to assure the CAT is working properly. Engineer level users may define the test specifications for each process tool and components. Finally, the Owner has full access to all controls including defining the security levels of the other users.



SYSTEM STATUS

The status view displays the active system with the components presently under test. Graphic representations of gas flows and valves opening provide a birds eye view of the overall configuration.

Setting up configurations for multiple process chambers is made simple by the pre-loaded defaults and copy configuration features. Each CAT system comes pre-loaded with factory specifications for most MFCs and manometer types. Selecting the model number automatically loads the default settings. Also, once a process system's configuration is completed, copying the configuration for like process systems is just a couple of mouse clicks away.

JUSTIFYING THE CAT

Return on Investment for the CAT

We recognize that there are only two reasons why any company will invest money in capital equipment. They do so either to make money or to save money. By far the predominate expenditure is on production equipment used for the manufacture of wafers, making money. A relatively much smaller amount is expended on making our existing production capability more efficient, or saving money. Many cost of ownership and return on investment formulas exist for production machines, but such models have been generated for diagnostic or test equipment. As such, it is much more difficult to justify the expenditure for this type of equipment, even though there may be great savings.

The CAT, in its various forms, has been in use for just over 10 years and there are now, over 180 VDS systems (the VDS is the previous model of the CAT) in the field. This experience has allowed us to develop a model of the return on the investment for a CAT system. This model by no means stretches credibility and in almost all cases we have used extremely conservative numbers. When real numbers are plugged into the formulas, the savings increase dramatically. The data regarding machine failure rates, MFC failure rates, and MFC failure types is abstracted from a variety of sources and does not rely strictly on any of our direct experiences.

The basic assumptions that we will use in our model are:

Average wafer value	$1,000
Wafers per cassette	25
Cassette value	$25,000
Average number of cassettes processed per day per system	5
Production value per day per system	$125,000
Average time between wafer processing and wafer inspection	2 days
Average number of machines serviced by a single CAT system	30
Average failure rate per machine per year	3
Total machine failure incidents per year	90

With these assumptions we have 30 machines processing an average of 5 cassettes of wafers per day. The value of the wafers processed per day in each machine is on average $125,000. We also assume that each of these machines has a process related failure 3 times per year. For the sake of this model we are ignoring mechanical and transport related problems, but 3 process related failures per year are still pretty conservative. The total number of process related failures on our 30 machines is then, on average, 90 incidents per year. We will also, for the most part, discount mantime requirements for the repairs being made, as they are insignificant to the overall cost associated with lost wafers and lost production.

Currently the single most popular diagnostic technique in use is the sacrificing of production wafers. Machines are diagnosed to be "broken" when during inspection a problem is found with the wafers produced. Unfortunately, and in most cases, there is not a 100% inspection done immediately after each process step, so there is some lag time between problem occurrence and the detection of the problem. On the basis of customer input, we have used 2 days as the *average* lag time between processing and inspection. Production proceeds produced during this lag period are called *Diagnostic Scrap*. These are wafers that are processed in a malfunctioning machine and whose only net value at the end is in informing us that the machine is non-functional.

Using our assumptions, the actual numbers follow:

Average production value per machine per day	$125,000
Lag between processing and inspection	2 days
Wafer value processed in this time	$250,000
Reworkable wafers	10%
Lost "Diagnostic Scrap" per incident	$225,000
Lost "Diagnostic Scrap" per year (90 incidents)	$22,500,000

As you can see, even from our modest assumptions, there is a loss of over 24 million dollars in diagnostic scrap per year. We will not address rework costs in this model, but even if you could rework 90% of these wafers for *free*, you would still have almost 3 million dollars in "Diagnostic Scrap".

Phase 1

Phase 1 of this model characterizes the reduction in Diagnostic Scrap that can be recognized by using the CAT in a comprehensive program of regular testing of critical machines and statistically based equipment maintenance.

Our assumptions here (based upon industry surveys) are that <u>greater than 75% of all process related problems are caused by a MFC malfunction</u>. Eighty percent of MFC malfunctions are generally calibration related and are not caused by physical damage to the device. For the sake of the model we will also assume that 5% of the remaining failures can be attributed to other vacuum related components such as pressure sensors and vacuum pumps.

The CAT allows each parameter of each of the several tests that it performs to have individual PASS/FAIL limits set in a Host Configuration file. These limits should be derived from an error budget for each parameter (such as gas flow or pressure) which are derived from the original response surface developed for the process. When the machine is incapable of successfully running the process within its process window, then a failure will be generated. If all components pass, then the machine should be able to run the process as designed. These limits are permanently stored in an individual Host Configuration file and may be recalled and used at any time.

By frequently testing the process machine, we can detect and track performance variations that will affect the process. Dangerous situations can be corrected *before* they impact a single production wafer. This frequent testing may require some additional manpower expenditures, but by eliminating 80% of the Diagnostic Scrap, it is well worth it.

Thus:

Diagnostic Scrap without CAT program	$22,500,000
Diagnostic Scrap with effective CAT program (80% reduction)	$ 4,500,000
Net savings -- Phase 1	$18,000,000

Phase 2

The second phase of our model involves reducing the mean time to repair, in particular, the diagnostic phase. Once a process machine has gone down with a process related problem, it must be diagnosed, repaired, and requalified before production can continue. The time lost in this process is generally lost forever. Although the wafers that are not run during this time will be run after the machine is fixed, we are displacing later production and thus, raising costs.

An alternate solution to this would be to have "spare" process machines. This is sometimes done for critical machines. This alternative is extremely expensive in terms of capital costs, doubles the maintenance costs, and introduces system matching difficulties (which are best solved with the CAT!).

The CAT presents a much more cost-effective solution. It will identify most (80%, using the numbers above) of the causes of our process related problems in about 1 hour of testing. Once these problems are identified, in many cases they can be corrected with a simple calibration adjustment. The CAT provides enough data that adjustment of both the zero offset and the gain (slope or span) can usually be done by the user.

Failure incidents per year (from above)	90	
Failures due to MFC or Vacuum Equipment	72	
Average time to diagnose problem (without CAT)		1 day
Lost production value per machine during diagnosis (per incident)		$150,000
Total lost production time during diagnosis (per year, 72 incidents)	$10,800,000	

CAT Diagnostic Time	2 hours
Diagnostic Time savings (Total per year)	66 days
Savings in production time during diagnosis	$9,900,000
Net Savings from Phase 2	$9,900,000

Phase 3

Phase 3 of our model involves reducing mean time to repair (actual repair). Once we have diagnosed the problem, the challenge is in fixing the machine and getting it back into production. For the sake of the model, we will assume that all parts are in stock and no parts must be delivered from outside vendors. If parts are required, this can lengthen repair time by 2-3 days, with a corresponding loss of production time. Data generated by industry survey and OEM equipment studies provide indications that between 20 and 50% of all MFCs do not meet specification as delivered. Most of these failures involve calibration non-compliance. Unless a comprehensive check is made of these devices before they are installed (as provided by the CAT System's off-line testing capability), much of the work involved in changing out equipment may have to be repeated.

We will also use some of the minimum manufacturer recommended times for MFC and gas line purging. It may be common to find situations where shorter purge times are used, but this will dramatically increase failure rates and can lead to some very extended repair times if gas jungles must be replaced due to contamination or corrosion.

MFC Replacement Time	
Purge time (deinstall)	6 hours
Remove MFC	1 hour
Reinstall new MFC	1 hour
Purge time (install)	6 hours
Test	2 hours
Total replacement time	16 hours
Requalification time after repair	2 hours
Time to repair machines (24 work hrs/day) (assuming no parts ordered and 72 incidents per year)	54 days
Re-repair rate	10%

Total Time Lost	59.4 days
Total Lost Production Value Due to Repair Time	$8,910,000

If 80% of the time, an *in-situ* recalibration will correct the problem and we use the CAT to pre-qualify MFCs, the net savings would look like this:

20% of 54 days (must replace due to damage)	10.8 days
80% of 72 incidents (80% can be recalibrated in-situ)	58 incidents
Total recalibration time	2.42 days
Total production time savings per year using the CAT to perform in-situ recalibration to correct 80% of the MFC failures	$6,927,000
Total Phase 3 Savings	$6,927,000

Summary

	Without CAT	**With CAT (savings)**
Phase 1 (*Discovery*)	$24,300,000	$19,440,000
Phase 2 (*Diagnosis*)	$10,800,000	$9,900,000
Phase 3 (*Repair*)	$8,910,000	$6,927,000

Many of our current customers use the CAT primarily during Phase 2 and 3. As can be seen by this model, there are significant advantages to using a full time diagnostic program that would generate the savings seen in Phase 1.

Even if only 10% of the savings actually predicted by this very conservative model is made, it is obvious that the returns on an investment in a CAT system and the effective test program are significant.

CASE HISTORY

The **VACUUM DIAGNOSTIC SYSTEM** (VDS) and the new model **CHAMBER ASSURANCE TOOL (CAT)** are the first convenient means of routinely measuring the performance of gas control systems in the semiconductor industry.

Since its introduction in 1987, some patterns have become clear and there have been many examples of the utility of the device. Several common observations made are:

1) Mass Flow Controllers frequently fail tests. Usually they are still functioning well and achieve stable flow, but their calibrations seem to have changed - perhaps by a partially blocked by-pass tube.

2) Capacitance Manometers seem to fare better on calibration checks, but their zeros are often way out of adjustment, particularly in process systems that do not have high vacuum pumps and hence the manometer cannot easily be zeroed.

3) The third common problem is with leaking process chambers. Here we have to distinguish between the normal leak rate (real and virtual) that a process system may have under good conditions, and an unusually high leak rate that perturbs the process.

Of even greater interest are some of the more subtle failures in gas control systems that the VDS and CAT have helped to diagnose and rectify:

A. A process system was giving poor results and conventional trouble-shooting techniques had failed to diagnose the problem. Manometers and mass flow controllers had been checked on off-line calibration checkers and found to be within specification.

   By contrast, the VDS found that the capacitance manometer on the process system was not behaving properly. This apparent contradiction was resolved when further checking revealed that the manometer power supply, on the <u>process system</u>, had failed. The VDS had correctly diagnosed that the <u>pressure measurement sub-system</u> was performing improperly even though the capacitance manometer as an individual component was satisfactory.

   We have subsequently seen many examples which have confirmed the need to test the sub-systems on the process system rather than just the individual components off-line.

B. It's common experience that "identical" process systems need to be set up somewhat differently to achieve the same process results. One particular example of this involved two single wafer oxide plasma etching systems side-by-side; one performing extremely well, the other having much lower selectivity over the underlying silicon and also requiring greater frequency of cleaning. Both systems were running the familiar $C_2F_6/CHF_3/He$ chemistry, and in trying to trouble-shoot the problem, all of the MFCs and manometers had been removed and had their calibrations checked, being replaced where necessary, until the gas control system appeared to be within specification. Still the process performance problem persisted.

   The CAT detected a problem with the CHF_3 Mass Flow Controller on the poorly performing oxide etcher. In this example, the flow rate was oscillating as shown in the accompanying diagram. Since the CHF_3 flow rate is important in controlling the balance of the chemistry between etch and deposition when the underlying silicon is exposed, it's possible to surmise that the system was similarly oscillating between etch and deposition, leading to the lower selectivity and great polyimide deposition observed.

The off-line calibration checker did not detect this problem since it measured average flow rather than the real-time dynamic behavior. And actually, in this particular case, even an instrument that does measure the real time performance of components off-line - the CAT - showed stable gas flow when the suspect MFC was tested off-line. Furthermore, replacing the MFC did not solve the problem on the process system. This was because the offender was the pressure regulator on the supply gas bottle and the process problem was immediately removed when this regulator was replaced. Without the CAT, it may have taken a very long time to diagnose this problem.

C. Another interesting MFC problem was observed in a plasma polymerization system. Repeatedly, the flow rate on one MFC would drop precipitously about 2 minutes into the process, as shown. This had a catastrophic effect on the process even though the gas concerned was argon. The downstream pressure control sub-system probably would have caused a compensating increase in the partial pressure of the gas when the argon flow suddenly dropped. In this case, the problem was removed with the mass flow controller.

D. In pump speed tests, we are primarily looking for degradation in performance over time, perhaps due to seal wear or oil contamination. However, the CAT can also be a useful diagnostic for the installation. One user was puzzled by a measured pump speed that far exceeded the rated speed of the pump even though the pump was about 50 feet away on another floor in a case.

Indeed, the remote location did prove to be the issue; by design, the CAT measures performance at the process chamber in all of its tests. These are the performance parameters that the process is sensitive to - and not, for example, to the intrinsic speed of the pump.

In this particular example, the HiVac valve was located immediately behind the process chamber. When the HiVac valve was closed, all of the pipe work was reduced to a pressure of just a few mtorr. Since the installation had been carried out with large diameter pipe work to minimize conductance losses, there was an extremely large volume of low-pressure gas in the pipe work. This meant that when the HiVac valve was opened, there was almost a "black hole" of vacuum. Indeed, the pumping system would probably have pumped very rapidly even with the pump switched off, at least for a short time!

This particular user had also been experiencing particulate problems and this was probably due to this extremely high initial pumping speed creating a sand storm of particulates. With the installation of a "soft pump" around the HiVac valve to suppress this initial high pump speed transient, the particulate problem was significantly reduced.

E. In yet another example of two "identical" process systems that performed differently, the CAT found that the pumping speeds in the two systems were considerably different. The user was aware that the two pump installations were quite different, but had reasoned that the automatic pressure control in the system would adjust the throttle valves so that the same net pumping speed would be achieved in each process chamber.

While this reasoning is correct under steady state conditions, it is not true under transient conditions when the throttle valve may open wide to eliminate a pressure surge, such as at the beginning of the process when the plasma-induced dissociation of the gas may cause an instantaneous doubling or more of the process pressure.

F. Finally, we heard about, but did not have the pleasure of participating in the following story: The apparent reduction in the volume of a process chamber and the simultaneous disappearance of a maintenance engineer's toolbox proved to be no coincidence!

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