MICRO

Ensuring process integrity by using direct-measurement technology in solvent hoods

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A case study demonstrates how fab personnel improved process control and reduced wafer scrap by switching from an inferred-flow system to direct-measurement flowmeters on solvent hoods.

W*afer processing requires the* use of proper amounts of chemicals during photoresist, etch, planarization, and cleaning steps. Manufacturing steps demand that appropriate combinations of chemicals, temperature, and time be repeated for every process cycle. Abnormal flow conditions can create process problems, such as temperature instability and particle generation, and can lower profits as a result of excessive equipment downtime, reduced throughput, increased defect densities, and increased wafer scrap. Abnormal chemical flow in a high-throughput fab can be disastrous. For example, a low-flow condition in a 20-wafer-per-hour process can cause an IC manufacturer processing wafers valued at $2500 each to lose $1,200,000 per day in revenues.

Abnormal flow conditions can have a variety of causes, including pump, filter, and valve or valve control issues; facilities difficulties; or human error. In order to maintain process integrity and minimize scrap, it is critical to detect and correct abnormal flow conditions as soon as possible. This article outlines equipment issues that can lead to chemical flow problems, focusing on the causes of flow anomalies and methods for detecting them. It includes a case study that involved chemical flow problems in solvent hoods at Texas Instruments' DMOS5-S wafer fab in Dallas, TX.

Inferred versus Direct-Measured Flow Rates

The flow of chemicals in many semiconductor wet process hoods is inferred

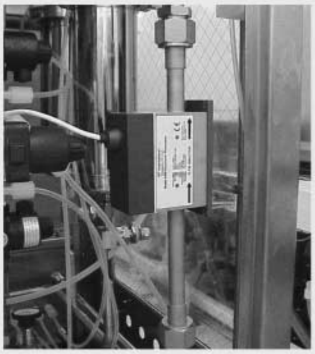

Figure 1: A direct flow-measurement unit installed in the fab (left) and the flowmeter's dual-channel display (above).

rather than directly measured. This is true not only for many solvent and acid hoods, but also for chemical-mechanical polishing equipment, bulk-chemical delivery systems, and other process equipment. When measured flow rate information is not available, the equipment user must rely on inferred flow rates. Often, inferred flow rates are calculated from the pump-stroke rate and are not necessarily an accurate representation of true flow.

At worst, relying on inferred flow rates can allow abnormal conditions to go undetected, which can result in misprocessing or wafer scrap. In addition to not detecting actual flow problems, inferred flow rates can create a false sense of security, because they can mask flow conditions that appear to be, but are not, within tolerance. For a hood to operate properly, the chemical recirculation system must be reliably monitored 24 hours a day to ascertain that flow and pressure are within specification, which, in turn, ensures that the process is under control.

Criteria for Selecting Direct Flow-Measurement Technology

Because semiconductor processes are challenging, finding the best flow-measurement technology for a given application can be difficult. It is therefore important to choose a flow measurement device that does not generate contaminants, has an electronic output to allow for automated flow monitoring, is chemically compatible with the process and robust enough to survive the process conditions, maintains accuracy under a variety of process conditions, and is easy to install.

Contaminant Generation. Chemicals used in the semiconductor industry can be very aggressive. They can damage components and cause them to generate solid or dissolved contaminants. Since the very purpose of installing flow measurement devices is to prevent incidents that can lead to expensive wafer scrap, it is important to choose a flow-measurement device that does not cause contamination problems.

Some flow-measurement devices are more likely than others to create solid and dissolved contaminants. For example, devices with moving parts have a tendency to generate contaminating particles even under standard process conditions. Processes involving high temperatures, aggressive chemicals, or liquids with a high solids content can cause components with moving parts to be vulnerable to particle generation.

Electronic Output. A flow-measurement device with an industry-standard analog output (voltage or current) is indispensable for automated equipment monitoring. An electronic output is the surest means for preventing scrap.

Process Compatibility. Before installing a new component, a qualification procedure specific to the process may be needed to verify materials compatibility. The use of high-purity materials for wetted parts is critical.

Process Accuracy. Since flow measurement is used to monitor processes, it is important to maintain flow-measurement accuracy under a variety of process conditions. Inaccuracies can cause abnormal flow conditions to continue undetected or cause false alarms.

The accuracy of devices that detect flow by transmitting sound waves can be affected by vibration, an excess of bubbles in the liquid flow stream, or the devices' proximity to noise-generating sources, such as solenoids or pumps. Devices that detect flow by measuring vortex generation can be affected by anything in the liquid that affects vortices, such as suspended solids or gas bubbles. Devices with moving parts become less accurate when suspended solids or bubbles entrain in and around the sensing mechanism.

Installation Considerations. Different flow-measurement devices have different installation requirements. Devices come in a variety of sizes, have unique fitting types and sizes, must be installed either vertically or horizontally, and may require straight lengths of tubing before or after the unit. Some devices should not be installed near certain other devices. For example, when installed near a connection that can leak corrosive process fluids, the flowmeter must be encased in a housing that is resistant to splashes and fumes.

Fluid viscosity and purity, process temperatures, feed pressure, and flow range must be considered when determining the best flow-measurement technology for an application. Furthermore, some technologies cannot measure flow if the chemical flows through double-contained or stainless-steel tubing.

Choosing the Right Flowmeter for Fab Solvent Hoods

The solvent hoods at DMOS5-S had originally been outfitted with sightglass-type flowmeters with no electronic flow measurement or SEMI equipment communication standard (SECS) alarm capability. (SECS is a computer-to-computer communications protocol that helps to automate electronic manufacturing facilities by allowing computer-controlled process equipment from a variety of vendors to communicate with host computers.)

Since the fab had been experiencing recurring hood problems, the hoods had evolved to incorporate a system that monitored pump-stroke rate. However, after a scrap incident caused by a faulty valve that allowed nitrogen to backstream into the chemical flow (while the pump-stroke rate remained normal), it became obvious that a better flow-monitoring method was needed.

In choosing a flowmeter that would meet the fab's application needs and pass internal qualifications, the fab personnel first had to ensure that the device would be physically compatible with existing equipment and processes. It had to be capable of operating above 60°C (140°F) at the normal operating pressure of the pumps. Preferably, it would be manufactured for high-purity applications and contain wetted parts that are compatible with the fab's process chemicals.

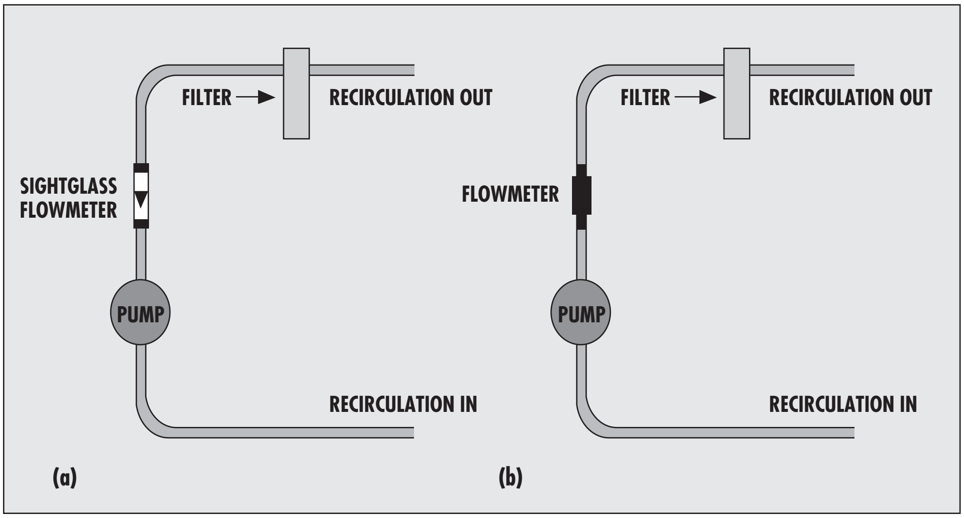

Figure 2: Schematic diagram comparing (a) the original sightglass flowmeter installation, and (b) the direct-measurement flowmeter installation.

After researching several direct-measurement devices, Texas Instruments chose to use an electronic flowmeter from NT International, a subsidiary of Entegris (Minneapolis). The company chose that device because it has stainless-steel construction, is easy to install, has flow and pressure analog outputs, and contains no moving parts. The device is pictured in Figure 1, and its programmable dual-channel display for local indication of process conditions is illustrated in the inset. Figure 2 contrasts the original sightglass and the modified flowmeter installation.

Using differential pressure technology, the direct-measurement device determines flow by measuring fluid pressure before and after an orifice in the flowmeter. The size of the orifice is determined by the application flow rate and fluid type. As described in Bernoulli's principle, fluid flow passing through an orifice increases in velocity, causing an increase in kinetic energy. The increase in kinetic energy causes a corresponding loss of static energy, reflected by a pressure drop across the orifice. An increase in flow causes a predictable increase in differential pressure. Flow rate is proportional to the pressure differential across the orifice:

$$\text{Flow} \propto k\sqrt{(P1 - P2)}$$

where k = a constant based on the application properties, $P1$ = pressure before the orifice, and $P2$ = pressure after the orifice.

Figure 3 presents a cross section of an NT International flowmeter that employs differential pressure technology. This unit is compatible with aggressive solvents at elevated temperatures, maintains 1% accuracy even in the presence of bubbles, can be installed in any orientation, does not require straight lengths of tubing before or after the unit, and has potted electronics with a splashproof National Electrical Manufacturers Association 4X enclosure.

In addition, the flowmeter provides analog signals for both flow and pressure. By utilizing a combination of flow and pressure outputs, users can detect several flow irregularities. This combination creates a redundant monitoring system, allowing the equipment operator or an automated system to monitor process conditions more effectively, while providing improved system diagnostics.

Installing and Qualifying the Flowmeter

Before ordering the flowmeter, investigators obtained reports from their chemical supplier to determine what types of perfluoroelastomer seals would be compatible with the chemicals used in the solvent hoods. Based on those reports, they selected a seal for installation in the flowmeter.

Prior to installing the flowmeter, the investigators had to confirm that it would not have a deleterious effect on existing process conditions. Therefore, they obtained chemical samples from the solvent hood to establish preinstallation trace-metal and chemical assay baselines. Then they ran test wafers to determine particle counts and trace metals using total reflection x-ray fluorescence, a nondestructive method for identifying and quantifying trace elemental contamination on the wafer surface. In addition, they recorded the pump-stroke rate and flow readings from the sightglass flowmeter.

Once the installation was complete, postinstallation readings were obtained for all the aforementioned parameters. Since no problems were found with any of the baselines after installation or over the following eight weeks of operation, the investigators decided to equip all of the solvent hoods with the same flowmeter.

Since the flowmeters had been newly installed in an aggressive application, the investigators planned to remove one flowmeter after two months of service and another one after eight months of service in order to disassemble and evaluate them and ensure that they were withstanding the process chemicals and temperatures.

Monitoring Equipment Performance

To monitor equipment performance, the investigators

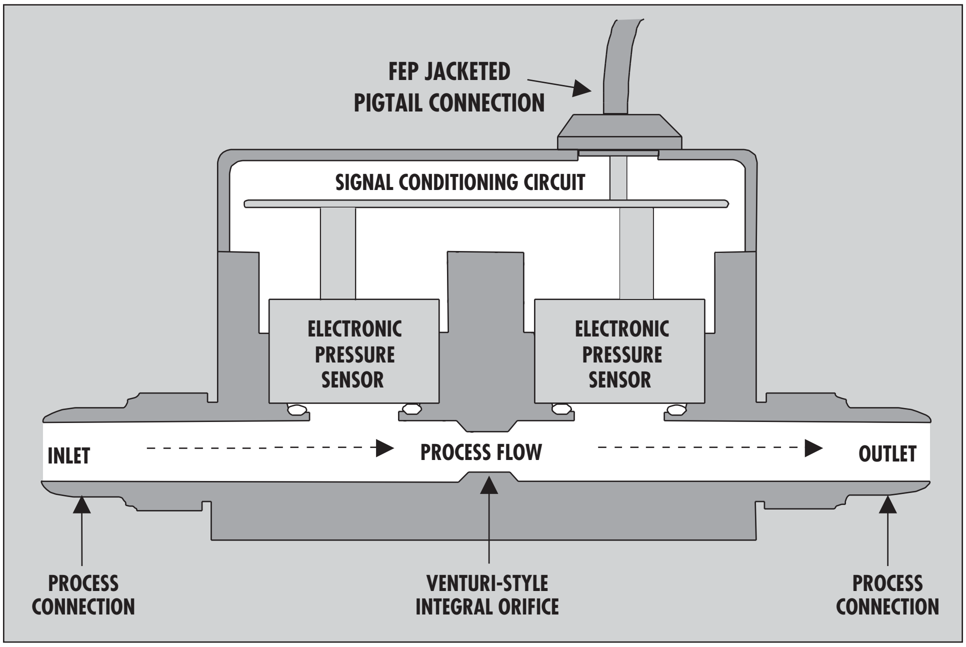

Figure 3: Cross-sectional diagram of the direct-measurement flowmeter.

input 4–20-mA flow and pressure analog output signals into the logic model of a tool interdiction and monitoring system (TIMS) developed by the equipment productivity services team of Texas Instruments in cooperation with DMOS5-S and DFAB1. TIMS performs round-the-clock fault-detection and data analysis, and its logic model, illustrated in Figure 4, monitors processes and places the hood in a down state if a low-flow or high-pressure condition is detected.

For example, if TIMS receives a signal from the pump controller commanding the pump to stroke, the flow must be above a defined level. If the flow is below that level for more than the time specified in the logic model, the hood is placed in a down state to allow equipment engineering personnel to investigate the problem. Thus, abnormal flow conditions are detected quickly, while nuisance alarms during chemical changes are prevented. In addition, if pressure rises above a defined level for more than the time specified in the logic model, the hood is placed in a down state.

The TIMS data-collection system incorporates several components. The two that are most often used to investigate problems are the real-time viewer and the historical viewer. Figure 5 illustrates the real-time viewer, showing normal process conditions for flow (upper trace), pressure (middle trace), and pump stroke (lower trace). The historical viewer enables users to recall data from the database to review process conditions, especially after faults have been detected.

The installation of the direct-measurement flowmeters enabled the investigators to detect, understand, and correct a range of process disturbances that previously had affected the solvent hoods:

- *Clogged pump guards.* Figure 6 presents an image of the TIMS historical viewer illustrating a quick drop in flow and pressure that was caused by a clogged pump guard while the pump-stroke rate remained normal. The guard is used on the suction side of the pump to protect it from debris, but it is susceptible to clogging over time. In this case, an insufficient amount of chemical at the suction side of the pump caused the low-flow condition.
- *Clogged filters.* By observing a rise in filter backpressure, the investigators were able to detect the onset of filter clogging and change the filter before an inadequate liquid flow rate could affect the process. Figure 7 shows an image of the TIMS historical viewer highlighting that the pressure output increased while the flow and pump stroke remained stable, indicating that the filter was nearing the end of its life. This test demonstrates that knowledge of pressure output is valuable for establishing a filter's normal flow-pressure relationship, which in turn ensures that a marginally functioning filter can be replaced before scheduled maintenance.
- *Failing shuttle valves.* When a pump's shuttle valve was failing, it stroked in an asymmetrical manner, creating an abnor-

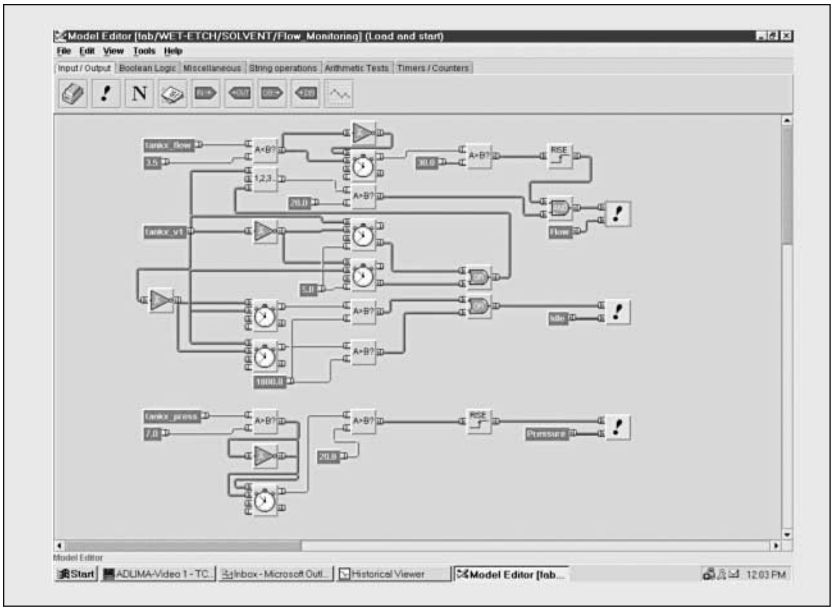

Figure 4: The TIMS logic model, into which signals from the flowmeter are input.

mal flow condition. Had the investigators not used the flow and pressure outputs from the direct-measurement flowmeters, the shuttle valve may have continued to operate inadequately until it failed completely and generated wafer scrap.

- *Improperly wetted filters.* When a hood is nonoperational or idle for an extended period of time, filters can dry out. In such cases, direct-measurement flowmeters can be used to detect the condition before returning the hood to service.
- *Low pump drive pressure.* The flowmeter detected a low-flow condition caused by low pump drive pressure, which prevented the pump from stroking properly.
- *Improperly seated filter.* On one occasion, the pressure output from the flowmeter was lower than normal. Investigation revealed that the filter situated after the flowmeter was not seated properly in the filter housing.
- *Faulty air interlock.* The hood was designed with an air interlock system so that when the panels are in place, drive pressure to the pump is applied. If a panel is removed, drive pressure ceases. An anomalous situation arose when a faulty air interlock caused the pump's drive pressure to cease intermittently. The resulting low-flow situation was detected and the problem rectified.
- *Valve failure.* The TIMS historical viewer image in Figure 8 shows a simultaneous loss of flow and increase in pressure caused by the failure of a recirculation valve. This condition could have caused a significant scrap event had it gone undetected. Although the pump could not circulate the chemical against the closed valve, its stroke remained normal, underscoring the advantage of using a direct-measurement system over an inferred-flow one.

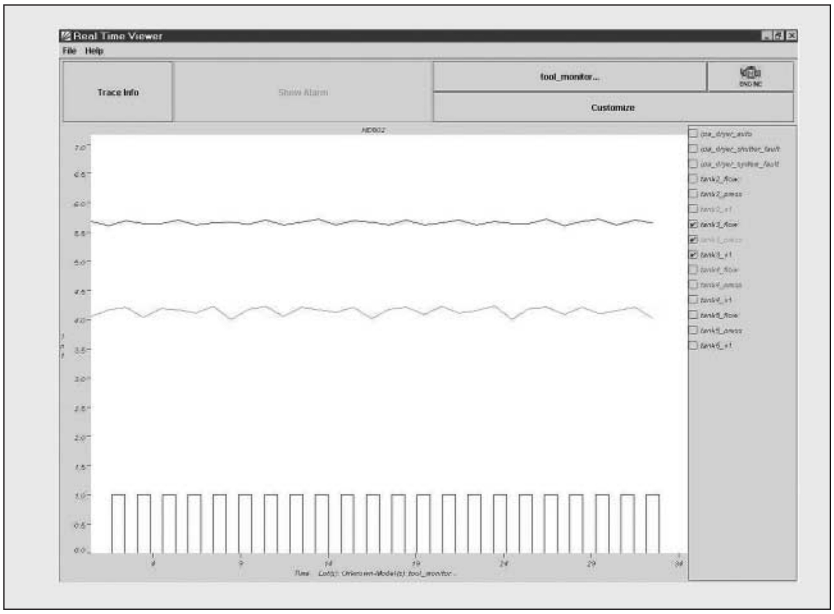

Figure 5: The TIMS real-time viewer, showing normal process conditions for flow (upper trace), pressure (middle trace), and pump stroke (lower trace).

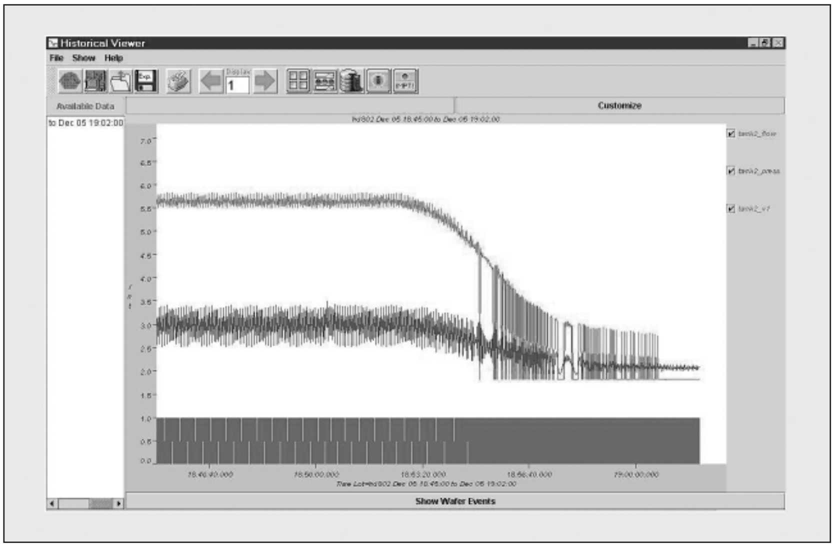

Figure 6: The TIMS historical viewer indicating the existence of a clogged pump guard.

Conclusion

The effort at Texas Instruments to continually improve chip manufacturing has led fab personnel to minimize improper processing, since low yields and scrap can be very costly and can affect customers. A scrap event prompted the company to investigate and implement electronic flow-measurement technologies on solvent hoods to ensure process integrity and prevent the recurrence of such events. That effort has significantly reduced the fab's vulnerability to flow-related problems and has increased process integrity, improved equipment performance, and prevented scrap.

One of the surprising benefits of having replaced an inferred-flow system with a direct flow-measurement one is that many problems were uncovered that previously had gone undetected. The direct-measurement flowmeters installed by the fab have met all application requirements and have been operating for more than two years.

Acknowledgments

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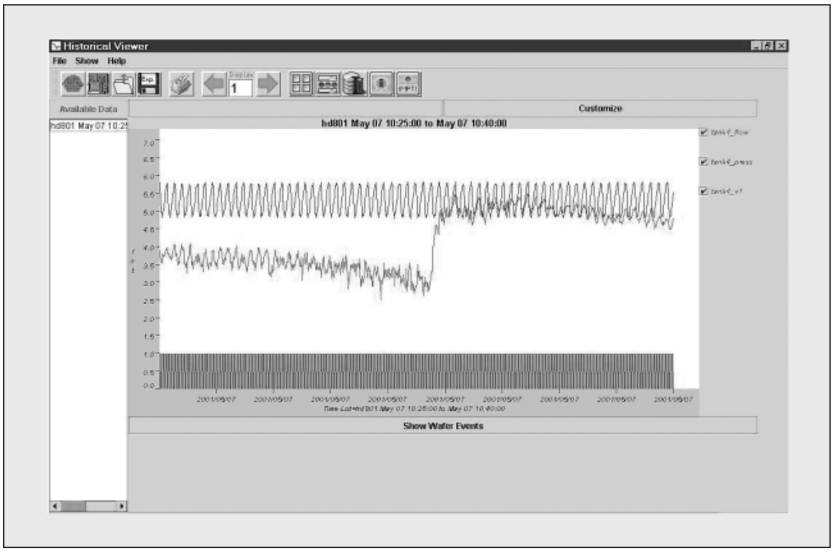

Figure 7: The TIMS historical viewer indicating the existence of a clogged filter.

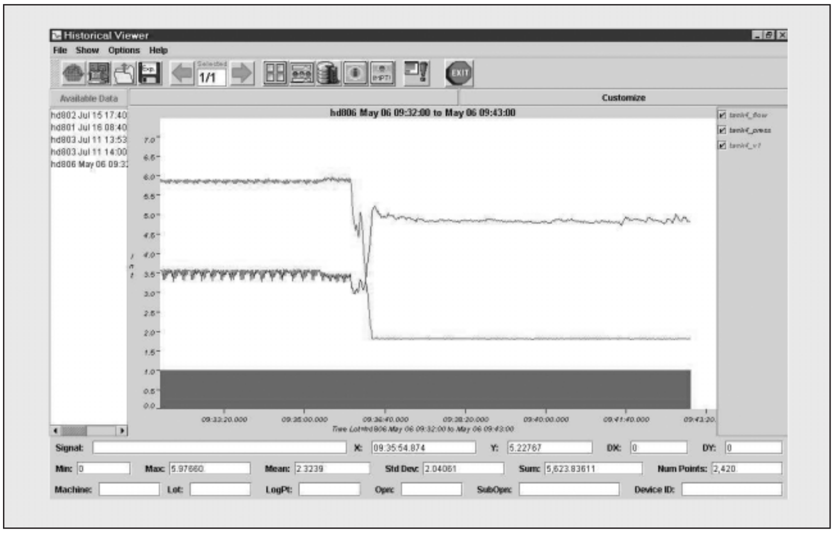

Figure 8: The TIMS historical viewer indicating a valve failure.

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