501-KH Speed Sense Valve Improvements

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Today, I will be discussing improvements to the Speed Sense Valve that International Power Technology is retro-fitting to 501-KH cogeneration plants in California.

The principal author, Jim Hamill, has been with IPT since its founding more than 25 years ago, and has been working on the KH since its inception. In addition to his ongoing technical contributions, Jim is IPT's Chairman of the Board.

Gary Owens, who is on the ATUA Board of Directors, is IPT's lead technician responsible for the implementation of these improvements.

I was responsible for controls engineering for the first six Cheng Cycle cogeneration plants in California.

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- About IPT
- SSV Background
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Today's presentation will provide a brief overview of IPT and some background on the Speed Sense Valve issue.

Then we will discuss IPT's technical approach to replacing the SSV with an electronically controlled valve, including a detailed system description.

Following a summary of the features and benefits of IPT's approach, we will be pleased to answer your questions.

IPT History

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1974	Founded by Dr. Dah Yu Cheng
1976	First of 46 U.S. and International Cheng Cycle Patents issued
	Most recent patent issued July, 2000
1982	IPT commercialized the KH Steam Injection Technology in conjunction with Allison Gas Turbines in Indianapolis.
1984 to 1987	IPT Developed 5 Cheng Cycle plants in California (36 MW)

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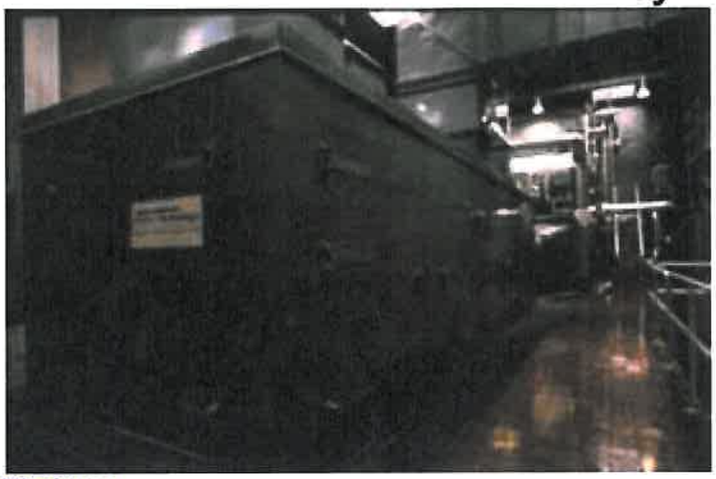
International Power Technology was founded in 1984 by Dr. Dah Yu Cheng, who was then a Professor of Engineering at Santa Clara University in California. The first of 46 U.S. and international patents covering the Cheng Cycle was issued in 1976.

The concept of dramatically boosting the power output and efficiency of Brayton cycle gas turbines by directly coupling the turbine to both sides of the Heat Recovery Steam Generator was highly radical and resisted by most engine manufacturers. It was only in 1982, when the Allison Gas Turbine Division in Indianapolis, recognized its merits, that the Cheng Cycle could be commercialized.

With the advent of the Public Utilities Regulatory Reform Act, IPT was able to secure the capital needed to develop 5 Cheng Cycle cogeneration plants between 1984 and 1987. These California plants were designed, developed, and in some cases, operated by International Power Technology, and they included

San Jose State University



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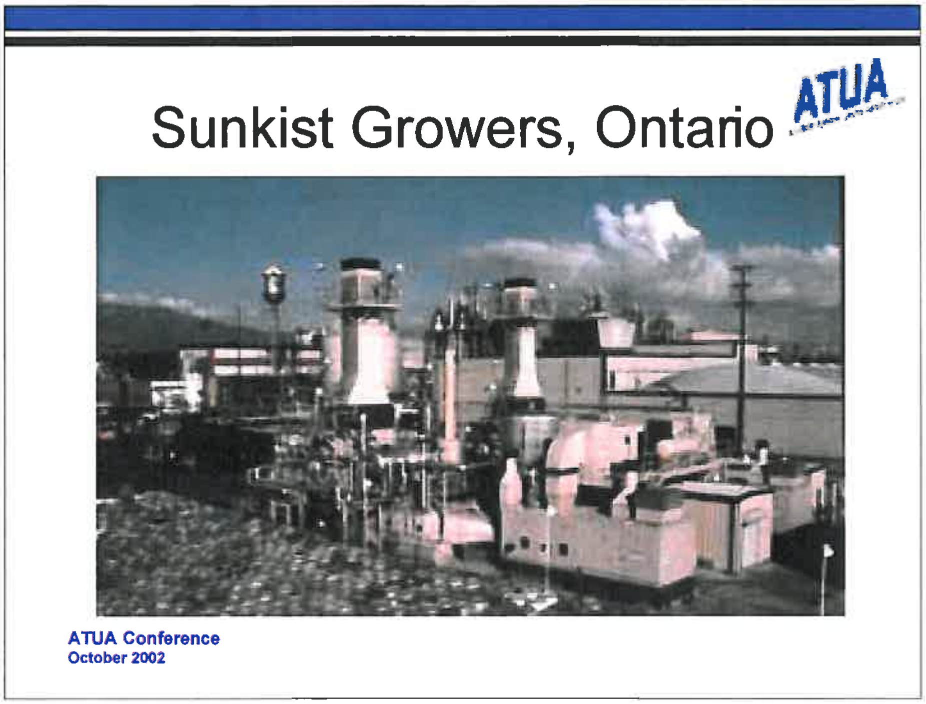
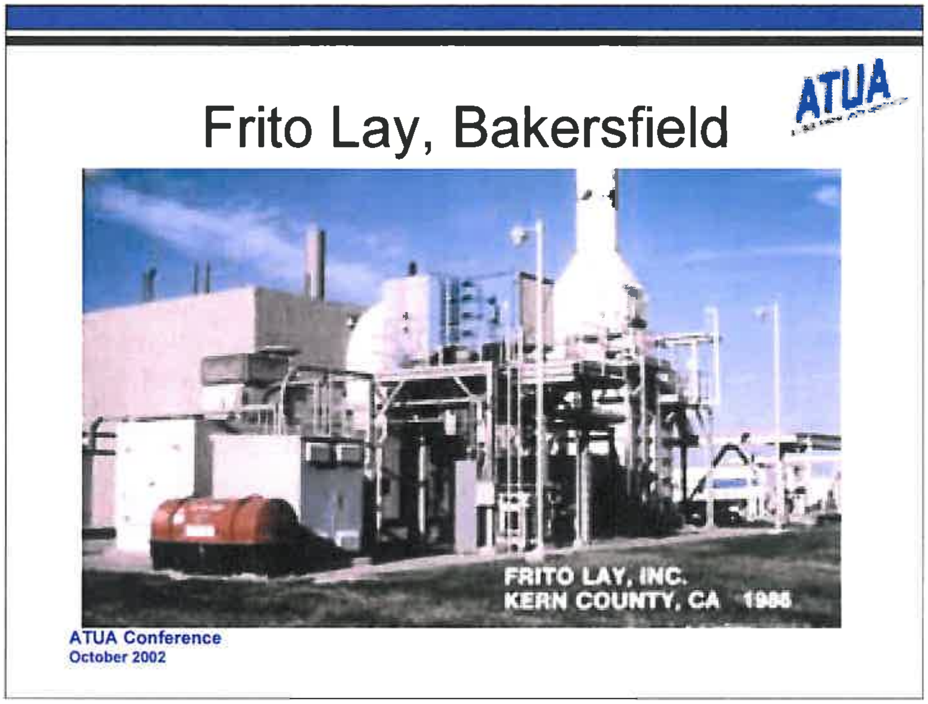
The first Cheng cycle plant, a single unit installation at San Jose State University, which is still operated by IPT.



A two unit Cheng Cycle plant at Sunkist Growers in Ontario, which IPT operated for many years, and which is now run by IPT alumni.



The one unit plant for Frito Lay in Bakersfield, which featured genset mounted controls, greatly decreasing the time required to test and commission a unit. To my knowledge, this was the first time that a Distributed Digital Control System was actually mounted on the genset skid to eliminate field installation of control cables.

Hershey Chocolate, Oakdale

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Next up was a single unit cogeneration plant at Hershey Chocolate in Oakdale.

SRI International, Menlo Park

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The last unit developed by IPT was the single unit plant at SRI International in Menlo Park, which we continue to operate.

IPT History

1987 to 1991	Licenses Cheng Cycle technology rights • U.S. Turbine (North America) • Voest Alpine (Europe) • Hitachi Zozen and KHI (Japan) • Detco (Australia)
1991 to 2002	Shifts focus: • power plant operations and management • worldwide licensee support • general power plant consulting
2002	• Re-enters project development business • Enters strategic partnership agreements

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Beginning in 1987, IPT licensed Cheng Cycle technology rights around the world to:

•U.S. Turbine for North America

•Voest Alpine for Europe

•Hitachi Zosen and Kawasaki Heavy Industries for Japan, and

•Detco, for Australia.

With licensees responsible for project development, IPT focused on

• power plant operations and management

• supporting our worldwide licenses

• and general power plant consulting

Recent events in California have allowed IPT to re-enter the project development business through strategic partnership agreements.

Current IPT Activities

- Distributed generation project development
- Turnkey power plant Operations & Management
- 24x7 emergency & field services
- Consulting & project financial analysis

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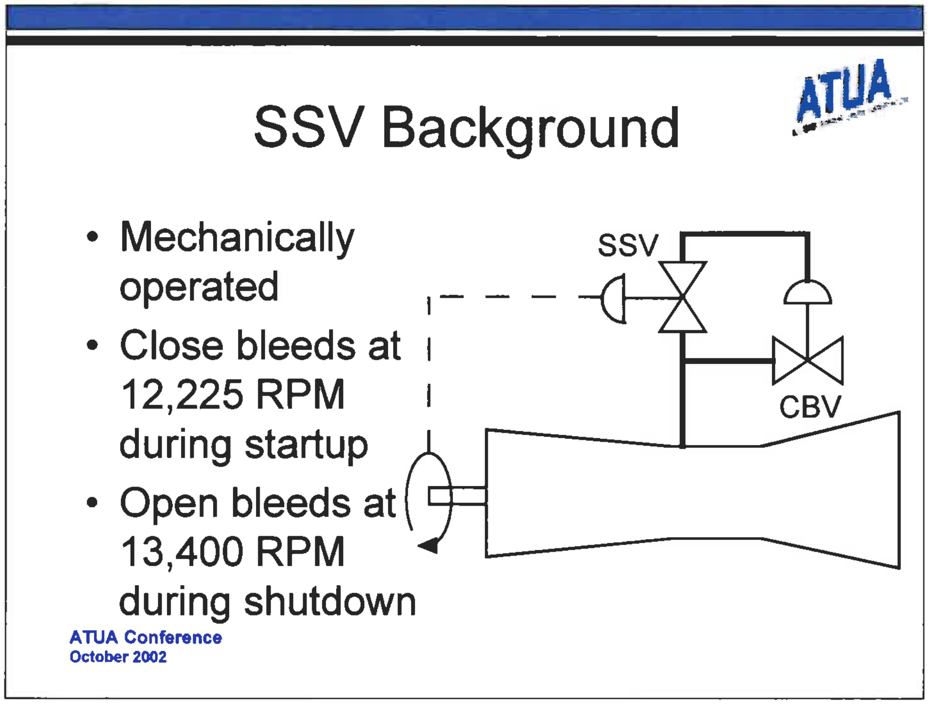
IPT now has activities in

•Project development for distributed generation, some of which we hope will be KH plants.

•We continue to offer turnkey power plant operations and management for both gas turbine and reciprocating engines.

•Round the clock service, for emergencies or scheduled outages.

•And consulting and project financial analysis, to assist in understanding the benefits and risks of installing and operating DG plants.



Now let's move on to the main topic, which is IPT's Speed Sense Valve improvements for the 501-KH gas turbine.

As you know, the SSV is a mechanically operated control valve, coupled to the shaft speed, that provides compressor discharge air to close the 5th and 10th stage bleed valves.

During startup, the valve closes the bleed valves at 12,225 RPM, and during shutdown, the SSV opens the bleed valves at 13,400 RPM.

For reference, the California 501-KH units operate at 14,600 RPM.

SSV Failures

- SSV sometimes opens bleeds at load
- 501-KH compressor damage
- >$100 k per incident (KH only)
- Root cause undetermined
- RR supports replacement with electronically activated valve
- Extends proven approach

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The SSV had operated reliably for many years, but recently there have been a number of failures, where the Speed Sense Valve opened the bleeds at load.

In the case of the 501-KH, with steam injection, these failures have resulted in compressor damage.

The damage is expensive, with direct repair costs sometimes exceeding $100 thousand dollars, and additional costs for compressor rental, emergency service, and replacement power. It is important to note that this kind of compressor damage is not experienced on non-steam injected engines.

The root cause of the SSV failures experienced during the last few years is undetermined, so Rolls-Royce now favors replacing the Speed Sense Valve with an equivalent electronically activated valve.

I should point out that an off-engine, electronically controlled bleed valve actuator has been used on various turbines by Rolls-Royce, since at least 1994, so the retrofit we are describing is an extension of a proven approach.

Retrofit Objectives

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- Maintain SSV/Bleed Valve Functionality
- Prevent Bleeds from opening at load
- Increase flexibility
- System Integrity
  - Integrated into engine controls
  - Fault monitoring
  - Protection

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In approaching the task of retrofitting the California KH units, IPT had a number of objectives.

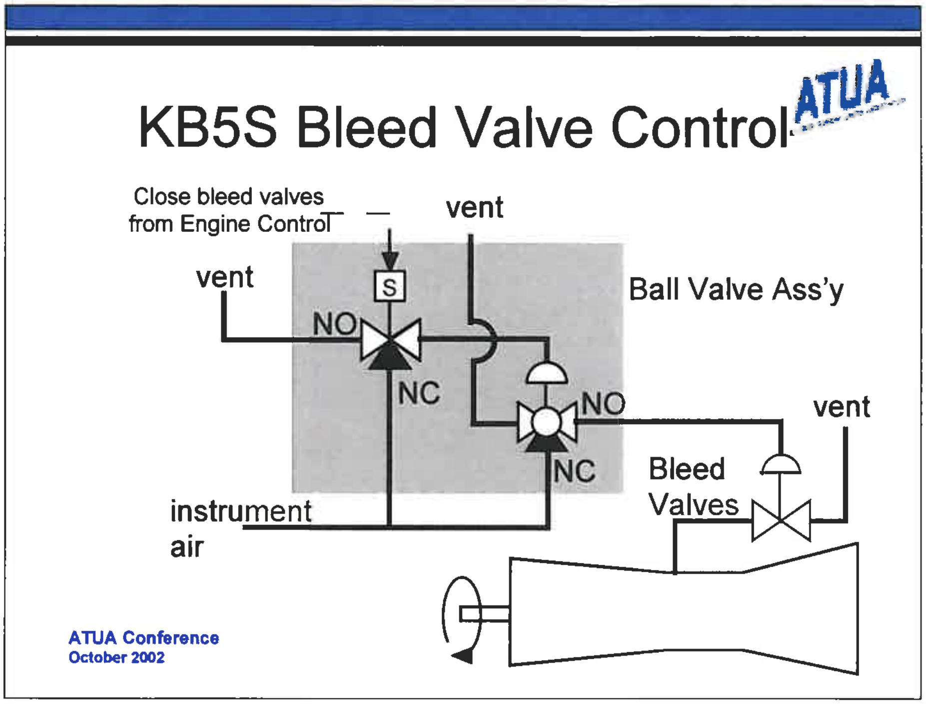
First, of course we wanted to maintain the functionality of the Speed Sense Valve and the Compressor Bleed Valves.

But the reason for the retrofit is to improve the reliability of the Bleed Valve Control. In particular, we want to prevent the bleeds from opening at load, because this has repeatedly caused surges and compressor damage at our installations.

Next we wanted to increase the operational flexibility of the bleed valve system. The most common need is to close the bleed valves during cold washing, but if we closed the bleeds during purge, prior to startup, we can drive more air through the HRSG, allowing for a shorter purge cycle. And we wanted to make sure that the bleed valves got closed for fire protection reasons.

Philosophically, we want to assure system integrity. By this we mean that the engine controls, in our case the Precision Digital Turbine Control System, has complete responsibility for operation and protection, including fault monitoring.

As the starting point for the retrofit, we used the Rolls-Royce 501-KB5S Installation Design Manual.



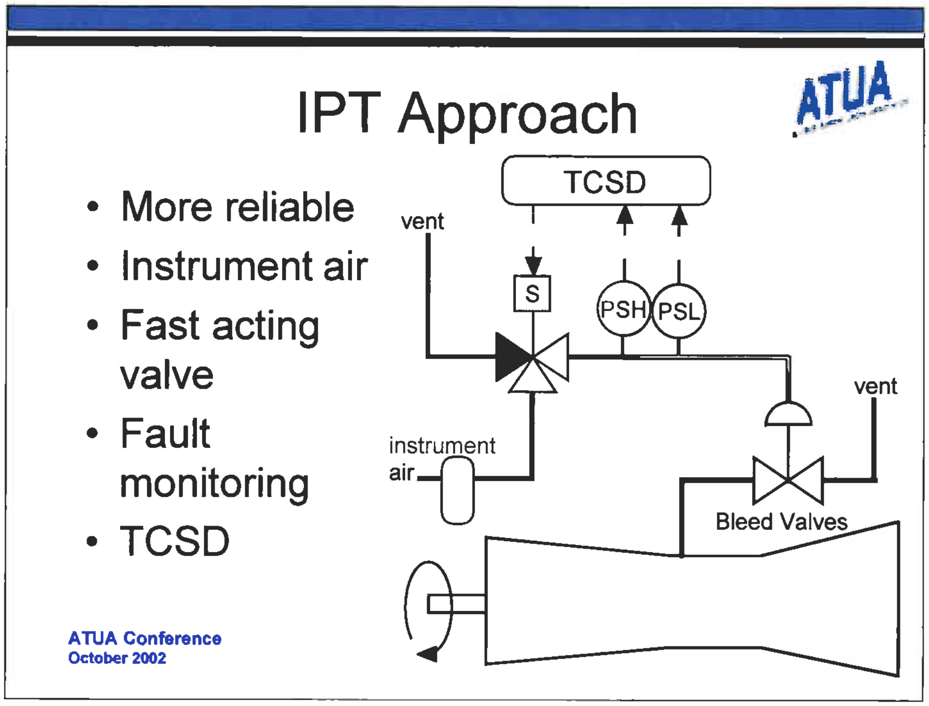
The current Installation Design Manual shows an electronic control opening and closing the 5th and 10th stage bleed valves.

A three way ball valve replaces the SSV, and motive force to close the bleeds is provided from an instrument air supply at 90 to 100 psig. Optionally, the air can be drawn from compressor discharge, as is done with the SSV, but this requires the addition of a cooler and coalescing filter.

Typically, the three way ball valve includes an air operator, with a spring return actuator. Air is supplied to the normally closed ports of both the pilot solenoid valve and the three way ball valve.

A signal from the Engine Control System, closes the vent of the pilot valve, allowing compressed air to enter the actuator of the ball valve. As the ball valve rotates, the spring is compressed and when open, air is then supplied to the 5th and 10th stage bleeds to close them.

When the pilot solenoid opens, air is vented from the ball valve and the energized spring returns the valve to its normal position, which vents air from the the top of the bleed valves, allowing them to open.



IPT's approach extends the KB5S approach with additional protective features.

•First, a solenoid valve is used to close the bleed valves when commanded by the TCSD. This solenoid coil is supplied from the same DC control power as the rest of the turbine controls. Since it's simpler we expect it to be more reliable than the three-way ball valve.

• Next, we use clean, conditioned instrument air, which is already available at our gensets for controlling the fuel gas block and bleed valves. We provide a coalescing filter, as extra insurance.

•The pilot operated solenoid valve is faster than the pilot operated ball valve, and it's also significantly cheaper than the ball valves.

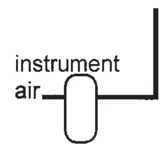
•We provide fault monitoring by installing a Single-pole Double-throw pressure switch between the solenoid valve and the compressor bleed valves.

•Finally, we interface this system to the TCSD and modify the Precision Engine Controls Corporation Digital turbine control system to control and monitor the bleed valves.

Let's go into more detail on each part of the system.

Instrument Air Supply

- Clean and cooled
- Coalescing Filter Backup
- Flexible
  - Compressor washing
  - Faster HRSG purge
  - Fire system isolation
- Minimum air pressure required



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Rolls-Royce provides for either Compressor Discharge Air or Instrument Air as the source for the motive force to actuate the bleed valves. IPT prefers to use instrument air, because it is already clean and cooled.

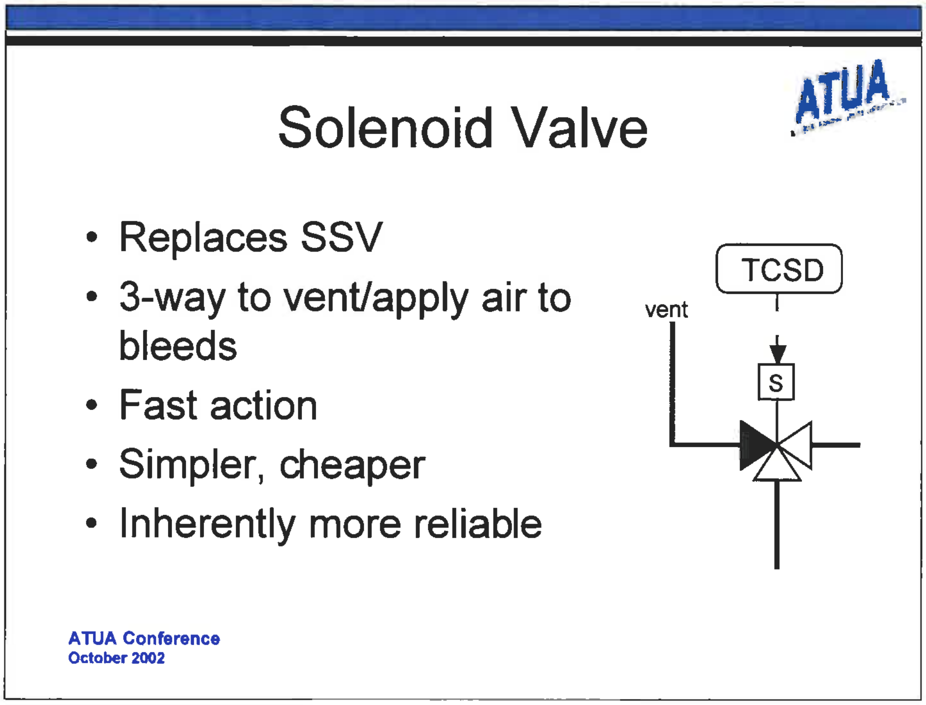
Nonetheless, we provide a separate coalescing filter on this line, because of the volume of air that flows through this system. The primary reason for using instrument air however, is the operational flexibility that it provides.

•The air supply allows the bleed valves to be closed when the turbine is shut down. This simplifies the compressor wash process, avoiding the need to manually connect a temporary air supply to close the valves.

•This also give the flexibility to close the bleed valves during the purge cycle, increasing the flow rate through the HRSG. This allows the purge timer to be shortened, resulting in faster starts, and less use of the starter motor.

•Another benefit is that if the fire protection system is actuated, the bleed valves can be closed. If the turbine was running, this means that less air is introduced into the engine compartment, reducing the oxygen available to a fire, and minimizing the displacement of fire suppressant gases. In addition, this assures that the engine compartment is completely isolated, removing a path for air to enter, or fire suppressant to escape.

However, it is critical that the instrument air supply pressure be adequate at all times. This requires coordination with the plant air system to assure that the air pressure doesn't droop excessively. And it requires that a protective trip be put in place, to shut down the turbine before the air pressure is reduced to a point that the bleed valves could open.



Now let's go into the details of the Solenoid Valve.

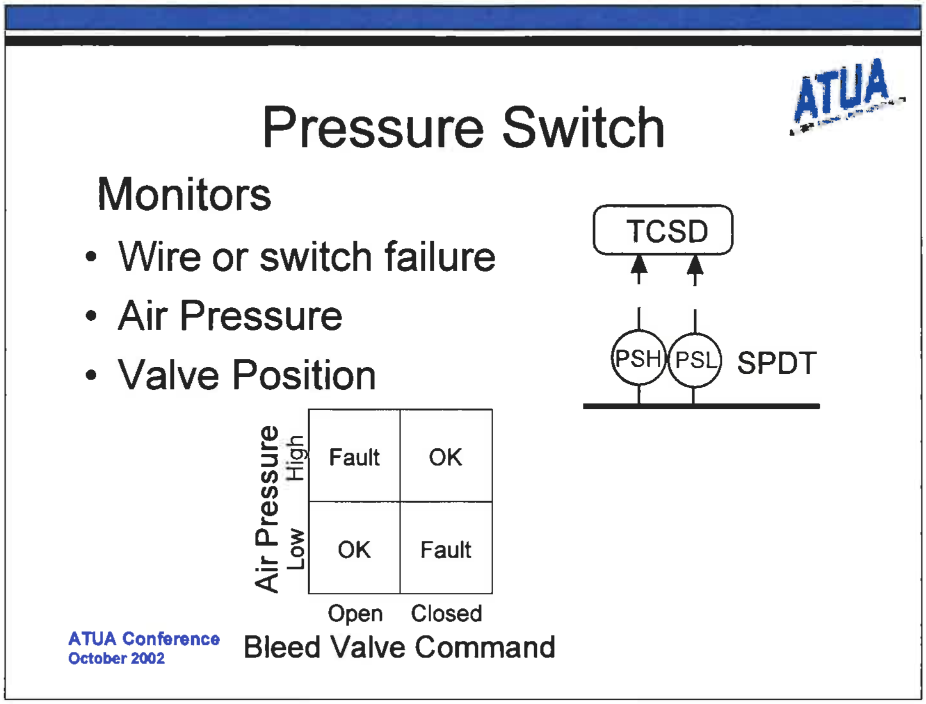
The solenoid valve directly replaces the function of the Speed Sense Valve, except now it is driven via a speed signal in the TCSD, which commands the bleed valves open and closed by venting or supplying instrument air.

The solenoid valve is pilot operated, in order to obtain a large port size for venting the air from the bleed valves. A direct acting valve, operated by our 24 Volt DC genset control power, would be limited to a smaller port opening.

The solenoid valve is faster acting, typically about 50 milliseconds worst case. This is about 10 times faster than the best case operating time of the Worcester controls 3-way ball valve often used in other installations.

The solenoid valve is also cheaper than a three way ball valve, and simpler to operate and maintain.

Because it is not subjected to hot compressor discharge air or engine vibration, the solenoid valve is inherently more reliable than the mechanical Speed Sense Valve it replaces.



IPT provides a Single Pole Double Throw pressure switch to monitor the air pressure between the solenoid valve and the bleed valves.

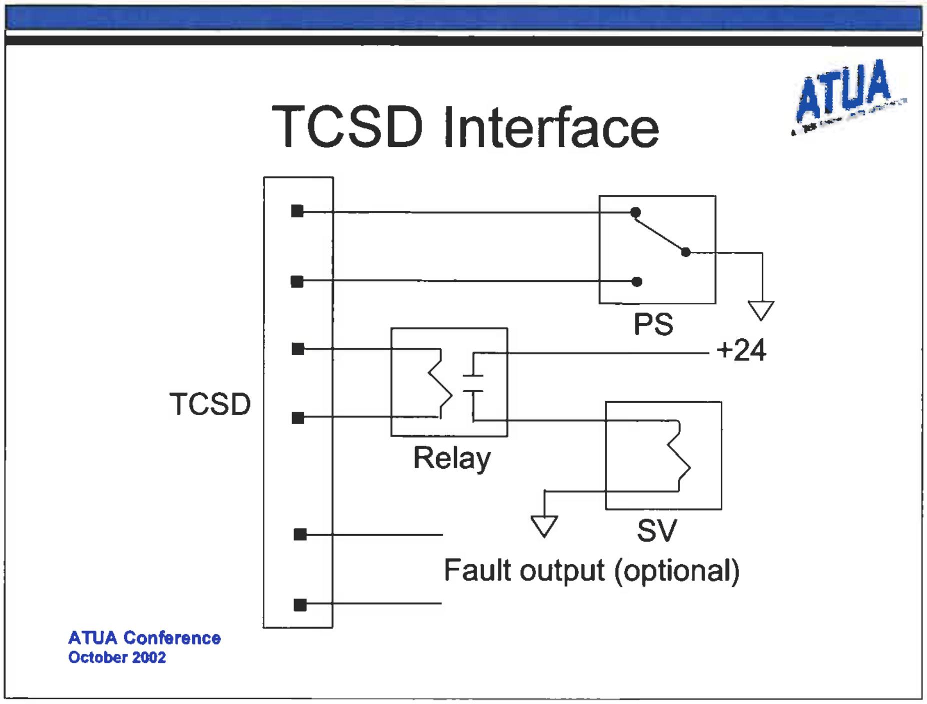
• Both contacts are wired to the TCSD, so that a failure of the switch, its wiring, or power source can be detected.

•The pressure switch is calibrated to change state at the instrument air low pressure trip, so the TCSD can shut the turbine safely before the bleed valves open, thereby protecting the compressor from a potential surge event.

•Finally, and perhaps most important is that this switch allows complete system functionality to be verified whenever the bleed valves are commanded to change state. This is illustrated in the truth table which shows the air pressure on the vertical axis -- either above or below the pressure setpoint. The commanded bleed valve position, on the horizontal axis, is either open or closed.

> •If the bleeds should be open, then air should be vented though the solenoid valve and pressure should be low, in the lower left box. If the pressure is high (after some brief time delay), there is a system fault, perhaps the solenoid valve has failed to vent the air.
>
> •If the bleeds are supposed to be closed, then pressure above the setpoint should be applied to the bleed valves, here in the upper right corner. If the air pressure is low, there is a system fault, perhaps the solenoid valve has failed to supply air.

The key point is that the functionality of the entire system is verified each time the bleed valves are commanded to move, that is, at each startup and shut-down.



Because the operation of the bleed valves is an engine function, we chose to integrate the control and protective functions into the Precision Engine Controls Corp. TCSD.

The I/O interface is straightforward. The Single-Pole Double Throw Pressure switch is connected to two digital inputs. As mentioned, this switch:

• changes state at the low instrument air pressure setpoint, allowing us to trip the engine before the bleed valves open;

• allows us to confirm that the solenoid valve is operating properly, by comparing the downstream air pressure with the commanded position;

• confirms functionality of the pressure switch, to make sure that a wiper is not stuck.

The digital output from the TCSD drives an interposing relay to provide the necessary current to actuate the solenoid valve.

An optional digital output is available for remote indication of a Bleed Valve fault condition.

Note that as with all other engine controls, power is supplied from the 24 Volt DC bus.

TCSD Control Functions

- Open Bleeds for these conditions
  - Startup: last ten seconds of purge through 12,225 RPM
  - Shutdown: between 13,400 to 3,000 RPM
- Mimics SSV
- Provides flexibility

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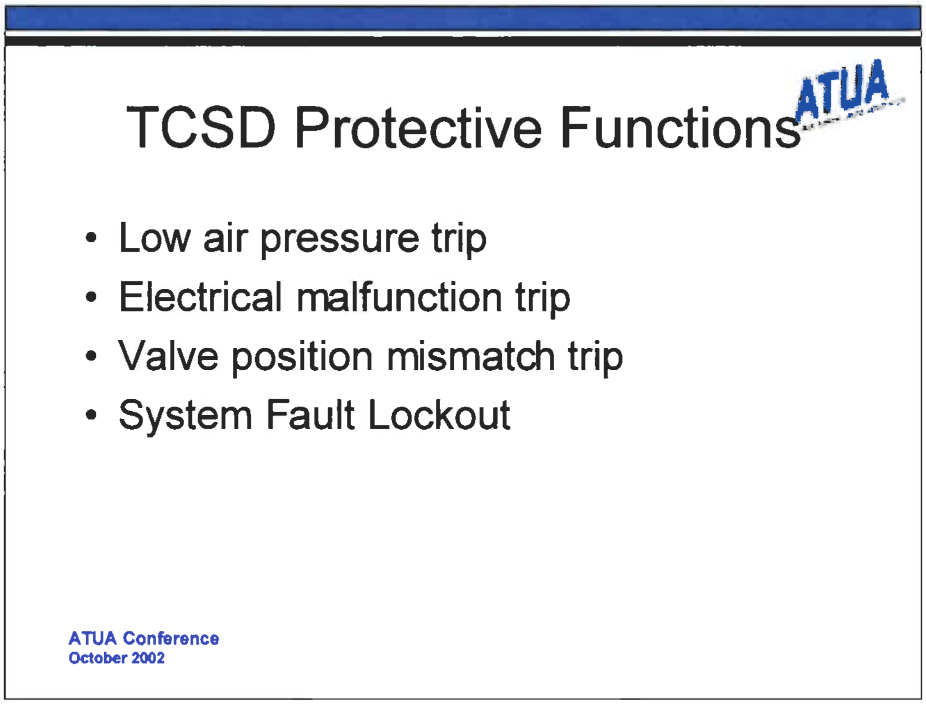
The TCSD control functions are straightforward, and similar to the SSV functionality. The bleed valves are commanded closed, except for two conditions:

Near the end of the purge cycle, the bleeds are opened in order to establish the same fluid dynamics conditions throughout the gas path, as is now experienced. The valves remain open until speed reaches 12,225 RPM, when they are closed for the final acceleration to synchronous speed.

On a shutdown condition, the bleed valves are opened when the engine slows to 13,400 RPM. They remain open until the engine slows below 3,000 RPM, when they are again commanded closed.

Closing the bleed valves while the engine is shutdown is critical for Cheng Cycle applications. Without this feature, air is drawn over the very hot superheater, potentially increasing the engine compartment temperature enough to trip the fire system.

These control functions mimic the operation of the SSV, but provide the operational flexibility, to perform cold water washes, purge the HRSG, and make sure the engine compartment is isolated for fire protection.



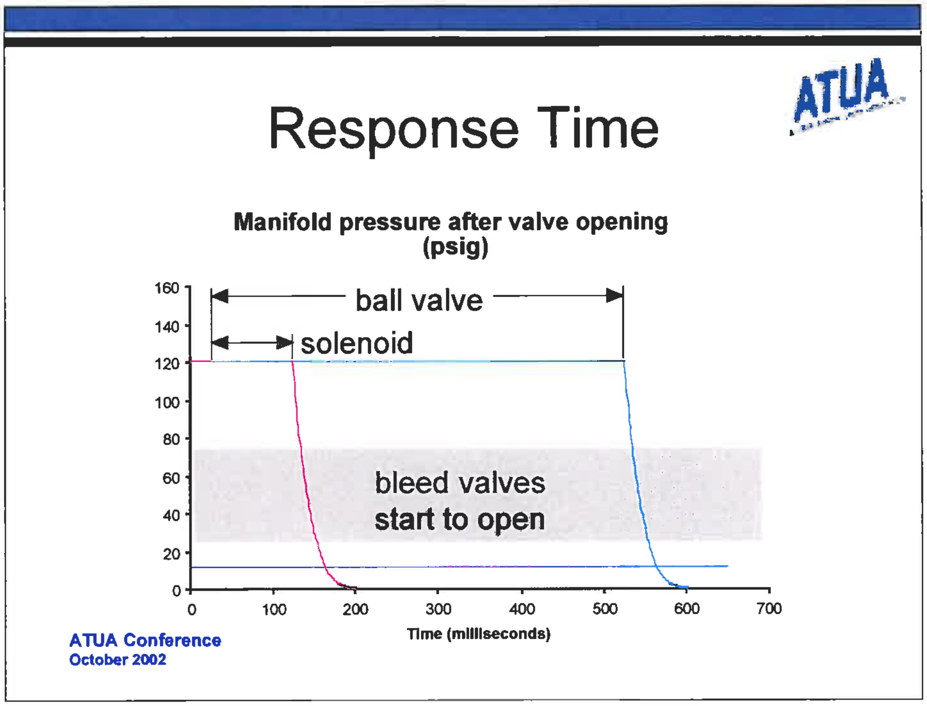
In addition to the basic operational control of the bleed valves, the TCSD provides important protective functions.

• First there is a low air pressure trip, that allows the turbine to be shut down before the bleed valves open unintentionally.

•As pointed out, the use of a single-pole double throw switch allows the TCSD to verify the integrity of the pressure switch, since it must change state each time the valves are operated.

•Also the TCSD continually compares the actual valve position, as indicated by the pressure applied to the bleed valves, with the commanded valve position. Any discrepancy lasting more than one second indicates a system fault, and results in a turbine trip. An important point to note is that this provides positive assurance that faults are identified during each startup and shutdown sequence. For example, if air pressure wasn't available, the bleed valves couldn't close during the purge cycle, and the mismatch would be detected. Likewise, if the solenoid valve failed to open the bleed valves during shutdown, the mismatch would be detected.

•A key reason for integrating all control and protective functions in the TCSD, is that it allows us to generate a system fault lockout condition. Any of the bleed valve trips would trigger the lockout, requiring the operators to investigate and fix the fault before re-starting.



The response time of the system is composed of three components.

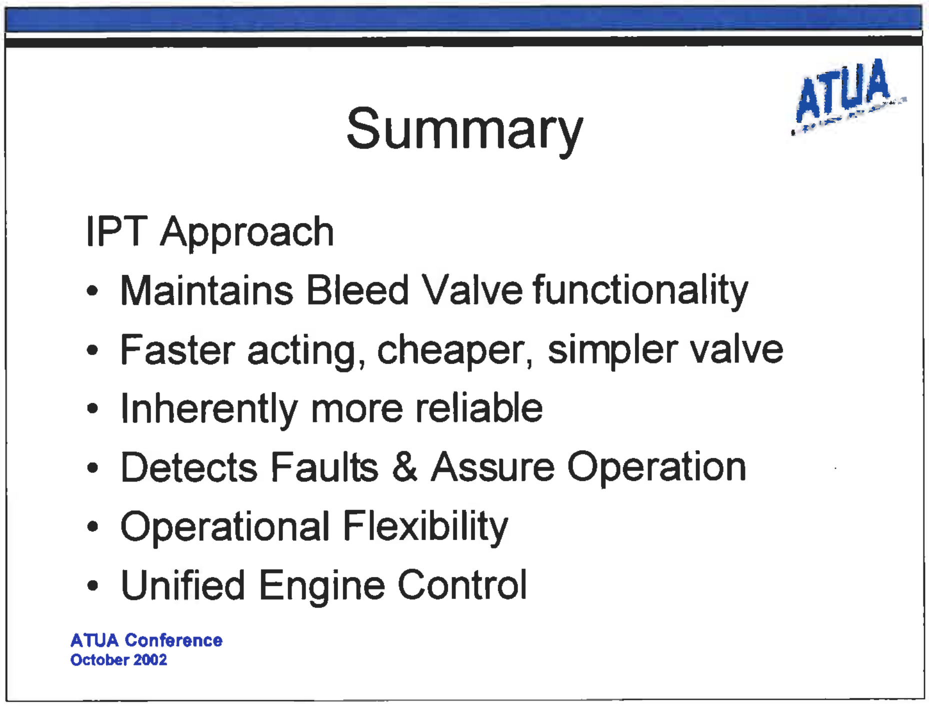
The first is an interposing relay, required because the control system cannot directly provide enough current to operate a solenoid. Of course, being purely mechanical, the SSV doesn't experience this delay. The worst case response time for the relay we chose is 25 milliseconds. Faster relays are available, but we chose this one for spares management.

Next is the time to operate the valve. A pilot operated solenoid valve, such as we chose, using a DC coil has a worst case operating time of 100 milliseconds. On the contrary, a 3-way ball valve has a **best-case** operating time of 500 milliseconds.

Of course air will start to blow-down as soon as the valves crack open, so the actual delay is not as long, but full flow through the valve isn't established until the valve is fully open.

This brings us to the blowdown delay, which is the time for air pressure on the bleed valves to decay to where the bleed valves can open. We have calculated the blow-down time for the valve, assuming that flow begins when the valve is fully open. Initially air flow is limited by the speed of sound. Only after air pressure decays to two roughly two atmospheres, will the valve flow coefficient govern flow.

At some point during the pressure decay, the pressure inside the compressor is sufficient to open the 10th stage and then the 5th stage bleed valves. The key point, though, is that even if air starts flowing when the ball valve has rotated half-way, its response time is significantly slower than the pilot operated solenoid valve.



To summarize:

• The IPT approach maintains the bleed valve functionality. The TCSD opens and closes the bleed valves at the same RPM settings as the current SSV.

• We use a faster acting pilot operated Solenoid Valve instead of a pilot operated ball valve. This valve is also significantly cheaper, and simpler, making for easier maintenance.

• The valve is inherently more reliable than the SSV, because it is not exposed to the same mechanical and thermal stresses.

•The system assures that the Bleed valve controls are working properly. It monitors fault conditions including air pressure, solenoid valve failure, pressure switch failure, and by monitoring the air pressure on the bleed valves provides positive assurance that the system is working on each startup and shutdown.

•IPT's approach also provides maximum operator flexibility, including compressor cleaning, faster HRSG purge cycles, and coordination with the fire protection system to isolate the engine compartment and reduce air flow that might feed a fire or displace inert gases.

•Finally, by placing the control and monitoring functions within the TCSD, IPT's approach unifies the Bleed Valves with the rest of the engine controls.

Benefits

- Maintain SSV functionality
- Improve SSV reliability
- Faster response
- System integrity assured
- Operational Flexibility
- Prevent 501-KH compressor surge from Bleed Valves opening at load

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In conclusion, here are the Benefits of IPT's approach to electronic control of the 5th and 10th stage bleed valves.

• First and foremost, it retains the functionality of the Speed Sense Valve, to open and close the bleed valves at the appropriate engine speeds, using the speed signal in the TCSD.

• The simpler solenoid valve improves the reliability compared to using a pilot operated ball valve.

• The overall system responds faster than a pilot operated ball valve.

• System integrity is assured by actively monitoring the mechanical and electrical mechanical components.

•The system provides the operational flexibility needed to conduct maintenance, start and run quickly and reliably, while coordinating with the fire protection system.

•Finally, the IPT approach prevents compressor surges resulting from accidental opening of the bleed valves while under load.