Monitoring system boosts efficiency

Deployed over a WAN, online system enables operators to develop automated control strategies based on real unit load.

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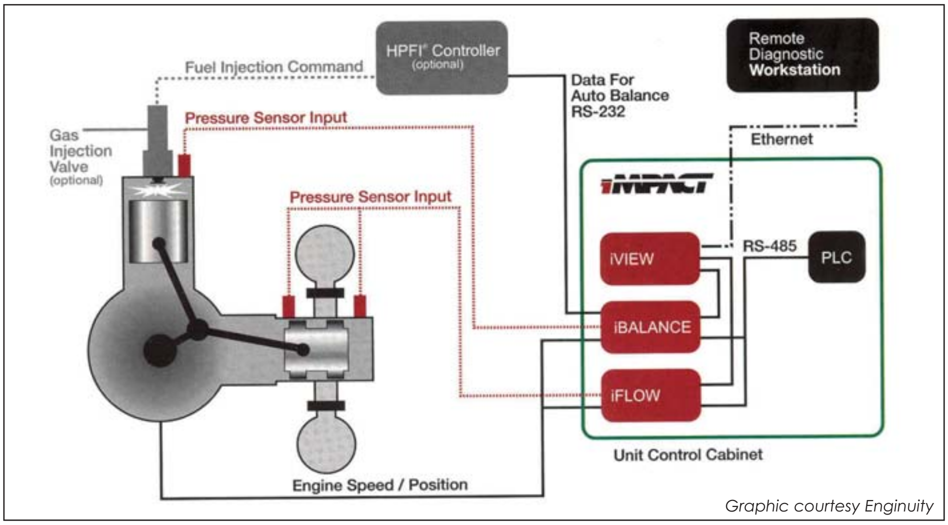
Williams Gas Pipeline (WGP) has developed an online reciprocating compressor and engine pressure monitoring system that enables station personnel to identify potential problems in advance and return the unit to proper operating condition sooner, resulting in increased pipeline capacity and lower costs.

Deployed over a wide area network (WAN), development of the monitoring system was made possible by installation of the Enginuity high-pressure fuel injection (HPFI) system on four stations along the Williams-Transco gas pipeline system, at Station 30 at El Campo, Texas; Station 40 at Sour Lake, Texas; Station 120 near Atlanta, Georgia; and Station 185 near Manassas, Virginia. The HPFI systems were installed on all reciprocating main units (total of 38 units) as part of an emissions reduction program. Currently, HPFI installation is scheduled for an additional 72 units.

Station personnel are now able to allocate their time more efficiently, because they are working on known problems rather than looking for potential problems on good cylinders. As they become trained to use the analysis software, the division specialists will spend less time assisting them in routine maintenance, and can concentrate their efforts on performance testing to provide the compression engineers with better data for the development of load models.

HPFI system

The Enginuity HPFI system uses iBalance and iFlow boards (manufactured by Windrock) for measurement and analysis of the engine and compressor pressure curves. The power cylinder pressure data required for injection control is supplied to the HPFI controller from the iBalance boards over a MODBUS interface.



Graphic courtesy Enginuity

Figure 1. Block diagram for a typical HPFI installation.

Board configuration, calibration, and archival data storage is done using the iView software running on an industrial PC installed near the engine. This software also displays the current data at the engine panel. The data archived by iView can be monitored and analyzed using Windrock's On-Guard® software to improve maintenance operations significantly.

The goal here is to describe the system hardware and software, show some examples of its remote analysis capabilities, and discuss how the analysts and compression engineers can use the data.

System description

Figure 1 shows a block diagram of a typical system. Pressure sensors on power and compressor cylinders are connected to iBalance and iFlow boards, respectively. An industrial computer running the iView software collects the data from these boards and stores it on its hard drive. On-Guard®, running on any computer on the network, can access the data for further analysis. The individual hardware and software components are described in detail below.

Power cylinders

Power cylinder pressures are measured using high-temperature pressure transducers with voltage outputs. Each iBalance board has inputs for TDC, crank angle encoder, up to 10 cylinders, a reference channel, and a channel for manifold pressure if desired.

For a 300-rpm engine, pressure measurements are made approximately every other revolution. The board firmware also calculates the average peak pressure, average peak angle, their standard deviations, and some additional statistical parameters used by the HPFI system. The user can specify the number of measurements used for the statistical calculations when setting up the iBalance board. This data is stored in predefined MODBUS registers on the board, and is read by the HPFI controller as needed. The RS485 port is used for communication with the iView software for configuration of the board, calibration of the sensors, and periodic download of the statistical data for storage and additional analysis. All data available on the MODBUS port is in the data packet sent to the iView software.

In addition to the statistical data, the iBalance board will send the current pressure curves to iView on request. The iBalance firmware checks the condition of each sensor as it makes the pressure measurement, and will generate a bad sensor alarm if the sensor is not working properly.

Compressor cylinders

Each end of a compressor cylinder is also monitored with a pressure transducer with a 4-20 mA output. The iFlow board accepts input from 10 cylinder ends, TDC and crank angle pulses, and, optionally, suction and discharge temperature thermocouples. If suction and dis-

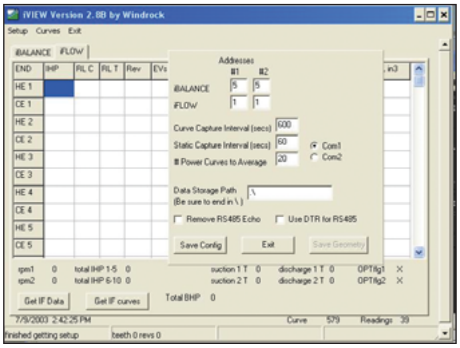


Figure 2. iView with main setup screen displayed.

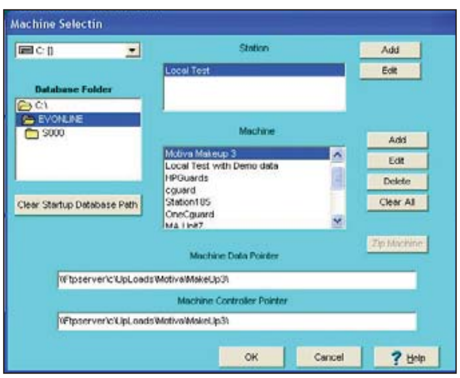


Figure 3. On-Guard® database setup panel.

charge temperatures are not measured, they can be provided to the board over its MODBUS interface. The firmware measures the cylinder pressures as functions of crank angle, and computes horsepower per end, maximum rod load in both compression and tension, minimum rod reversal, suction and discharge toe points, volumetric efficiencies, flow, flow balance, theoretical discharge temperature, and clearance volumes for the cylinder. This information is available in the MODBUS registers of the board, and is transmitted over the RS485 link to iView on request.

Data collection and storage

The iView program is used to set up the boards, calibrate sensors when needed, and display and archive the data. In these installations, iView is running on a Pentium 4 based industrial flat-panel computer mounted in a cabinet near each unit. Depending on the date of installation, these computers run either Windows NT or Windows 2000 Professional. The computers are connected to the plant local area network, and are configured to log onto the network automatically and to start the iView software on bootup. IView uses the built-in serial port (RS485) of the computer to communicate with the iBalance and iFlow boards.

The main iView setup screen is shown in Figure 2. The addresses of the boards on the RS485 link are entered in the boxes near the top of the screen. These addresses are also the MODBUS addresses of the individual boards. iView will address two iBalance and two iFlow boards (20 power cylinders and 10 compressor cylinders). Data storage intervals for the static data and curves are entered in the appropriate boxes. The choice of serial port for the system is chosen with the radio buttons to the right of the storage intervals, and some additional communications parameters are selected with the check boxes above the buttons at the bottom of the screen. The Data Storage Path box contains the path to the directory where the data for this machine should be stored. The "Store Config" button saves the board setup and address information on the local hard drive. "Store Geo" uses the board configurations to generate the geometry database for the software's analysis program.

Networking considerations

Each unit has a dedicated computer for data acquisition and monitoring of the unit operation. These systems are connected to the plant local area network (LAN) and to the company WAN. The consequence of this is that any Williams user can have access to the data stored on the local machines. Access to the data is controlled by the system administrator, who defines groups of users who have the rights to work with the data for specific machines. Specifically, if desired, station personnel can have access to the units at their station, division personnel can have access to units in their division, and corporate users can have access to all units.

Analysis software

On-Guard® software is used to monitor data and provide remote analysis capability for the individual units. Every user with access rights to the data has a copy of the software installed on his computer. When running, the software scans the data from the units that it is configured to monitor at fixed intervals. Specification of stations and machines is done in the database setup window, as shown in Figure 3. The "Add" and "Edit" buttons allow the user to define the station and machine names. The pointers in the lower part of the screen contain the directory name or UNC name where the data is stored (the UNC name is the name that the network uses to refer to a specific computer and directory on the network). The operating system handles the details of finding the directory and providing access to the database files.

Case studies

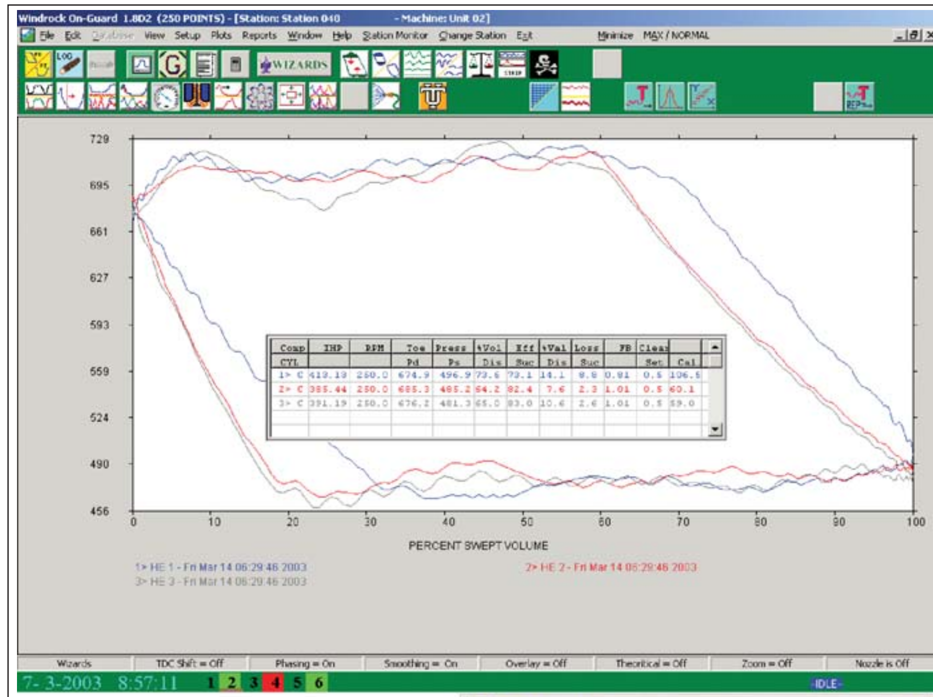
Three examples can be used to show how this system is currently being used to monitor mechanical and performance conditions on the Williams-Transco pipeline. Station maintenance personnel are responsible for the condition-based maintenance program. They have an oscilloscope and appropriate sensors to support this program, and are required to collect power and compressor data from all main units based on the number of hours of unit operation. The personnel then analyze this data to determine unit condition, and perform any needed repairs. They also have access to the analytical software, which is continuously running on a station computer. While the station personnel are not trained to use the advanced analysis features of the software, they have been shown how to scan through the various panels to view the current data from the on-line system.

Station 40, Main Unit 2

The division-level technical specialist has access to the data from this unit through the Williams network, and routinely scans the panels for the monitored units in his area. In this case, he noticed that the flow balance for the head end of cylinder 1 on unit 2 was significantly low, indicating a possible discharge valve leak. He notified the station personnel of the leak and continued monitoring it remotely.

The pV curve for the cylinder before repair is shown in Figure 4. In this case, it is fortunate that the other two cylinders on the unit were operating with the same clearances so that the curves for the three cylinders can be compared directly. The HE1 curve shows a significant discharge leak. The table in the plot gives the results of the performance calculations performed by the analytical software. The Leak Index windows below the plot are the results of additional performance calculations done to identify cylinder faults. This index clearly indicates a leaking discharge valve.

Mechanical inspection by station personnel indicated a valve with a broken gasket and one missing poppet. The valve was repaired and the unit returned to service. This discharge valve leak



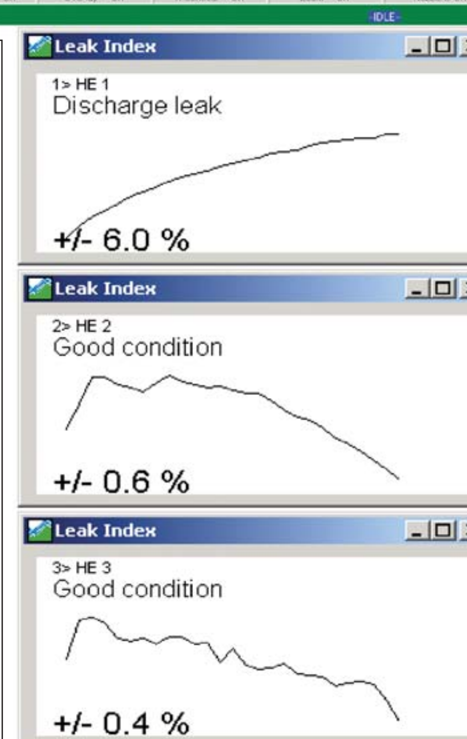


Figure 4. Discharge leak from Station 40 Unit 2. Head end data for all three cylinders on this unit is plotted for comparison.

resulted in a loss in capacity for the unit. Further analysis of the data will allow the analyst to easily compute the lost capacity, and determine what the leak is costing the company.

Station 120, Main Unit 15

The station maintenance personnel noticed an alarm on the flow balance for the head end of Cylinder 2 of Unit 15 when scanning the panels of the software. Like Station 40, this group has an oscilloscope for their condition-monitoring program. Analysis of the pressure curves taken by the online system showed a definite discharge valve leak in this end, and the valve was repaired. Figure 5 shows the pV curves for this end before and after the repair, taken from the online data. The pV diagrams are shown with theoretical overlays indicating the expected behavior. Note that before the repair, during expansion, the cylinder pressure drops much more slowly than would be expected, a classic sign of a discharge valve leak. The Leak Index also indicates a discharge valve leak. Prior to the repair, the flow balance was 0.91; after repair it has increased to 0.96. Careful inspection of the curve from the repaired cylinder indicates that there may actually still be some slight discharge valve leakage.

While inspecting this unit, maintenance also found a packing leak of approximately 2 ft^3/min. from Cylinder 1. Plotting the curves from the crank end of Cylinder 1, and calculating the performance data indicate that there is either a suction valve leak or a packing leak in the cylinder. In this case, the station personnel used the information available from the online system to prompt them to check the condition of their unit. Their data confirmed what the online system had reported, and they promptly repaired the unit.

Station 185, Main Unit 10

In May, the technical specialist for this district was at Station 185 to perform periodic emission testing. He noted that the emissions from Unit 10 were higher than expected. iView, running on the computer at the unit, indicated that the unit horsepower was 2,079 hp, significantly higher than the 1,867 hp used by the automation team for this load step. Because of this horsepower difference, the specialist returned with a portable analyzer to investigate the problem. The cylinders on this unit have single, large HEOB unloader pockets. His portable data indicated that when the unloader was opened, the pressure waveforms did not change, even though the indicator stem on the unloader was moving. In addition, the clearance volume calculations from these traces indicated that the clearance was not changing. His conclusion was that the unloader was not opening. Station maintenance personnel verified his conclusion, and repaired the unloader. The horsepower indicated on the iView panel then dropped by approximately 120 hp. In this case, the station personnel had the scope capability to locate the problem unloader. It was not known if this problem had occurred since the last scheduled inspection, or if it was missed at that time.

Because this cylinder end has a single large pocket, the problem can be diagnosed from the online data. Compressor Services, Houston, Texas, was inspecting the online data at the same time the portable data was being collected, and independently came to the same conclusion. Figure 6 shows the report generated from curves taken prior to the repair. The GPSA-calculated suction and discharge clearances, shown in the last column, are much smaller than the clearance set for this unit, as listed in the fourth column. The bhp reported is 2,111 hp at 331 rpm, and the N ratio for that cylinder is high. Inspecting this report more carefully, it can be seen that the N ratio for the crank end of Cylinder 3 is also high, and the calculated suction and discharge clearances do not agree. This indicates that the analyst should also look closely at this cylinder end for a potential problem.

After repair, the calculated clearances agreed with the set clearance, and the N ratio was much closer to 1. The reported bhp is 1,983.3 at 330 rpm, a reduction of 130 hp from the repair. This value is still higher than the 1,867 hp predicted by the load models used by the automation team.

Analysis of this fault was possible because there are only two possible clearance values for this cylinder. Load step information cannot be stored with the dynamic data because it is not available to the system. If the load step were available, the software could look up the clearances in its load step table for more accurate performance calculations.

Conclusions

The cases above show that the online system provides the stations with the ability to identify problems before they would be found with the existing condition-based maintenance program. Routine inspection of the online data will allow station maintenance personnel to identify unit problems when they occur, not at the quarterly oscilloscope inspection. If this information is used promptly, the unit can be repaired sooner for less capacity loss and more efficient operation of the station.

At this time, the station personnel have not been trained to use the software's analysis features. However, both of the valve cases discussed above were first noticed because an alarm on the flow balance was shown on the panel display of the software. Once the station was aware of the potential problem, the leaking valve was easily found with the existing scope equipment. As the station personnel gain confidence in the data from the online system, and learn to use its analysis features, they will find less need for the periodic scope inspections. Performance problems will be identified using the online system; oscilloscopes and portable analyzers will be taken to the engine room only when needed to troubleshoot the problem. Oscilloscope data will be taken on cylinders with problems, rather than wasting time looking at all cylinders, most of which do not have problems. The station personnel will be able to assume more responsibility for station performance, allowing the district engineer to focus his efforts on testing to support the performance models needed for automated pipeline operation.

The unloader problem discussed in the third case would have been found during the next periodic scope inspection. While inspection of iView panel display pointed to a problem, identification of the cause required a more thorough analysis of the compressor. Diagnosis of the compressor and identification of the fault through the online system was possible primarily because the cylinder end had a single large unloader. If the system were to provide loadstep information, the software would then be able to provide better analysis of the compressor cylinders. Efforts are underway to implement this capability.

In the short term, efforts will be made to incorporate load step information into the software, to extend its analytic capabilities. Over time, there will be two extensions to the system. First, additional features will be provided to help station personnel determine the economic value of a repair. For example, in the Station 40 case above, the lost capacity from the leaking valve can be computed easily. This loss has a cost associated with it, from increased fuel costs from the additional horsepower needed to compensate for the lost capacity, to increased emissions, and increased wear. There is also a cost for the repair in replacement parts, lost run time, and purging. When is the leak bad enough to justify the repair cost? It is hoped that in the future, the analysis software will be able to help station personnel make this decision.

Second, since the iFlow boards provide cylinder-by-cylinder horsepower calculations, this information could be used to close the feedback loop for the control system. By reading the actual delivered horsepower, the automation team could know exact operating conditions of the unit, rather than depending on a load model that assumes that the cylinders are in good mechanical condition. This will allow the automation team to develop a control strategy based on real unit load, to maximize pipeline efficiency and minimize costs.

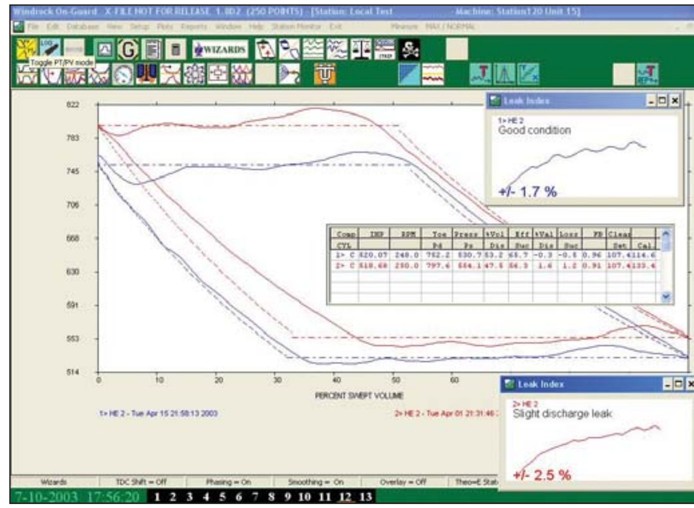
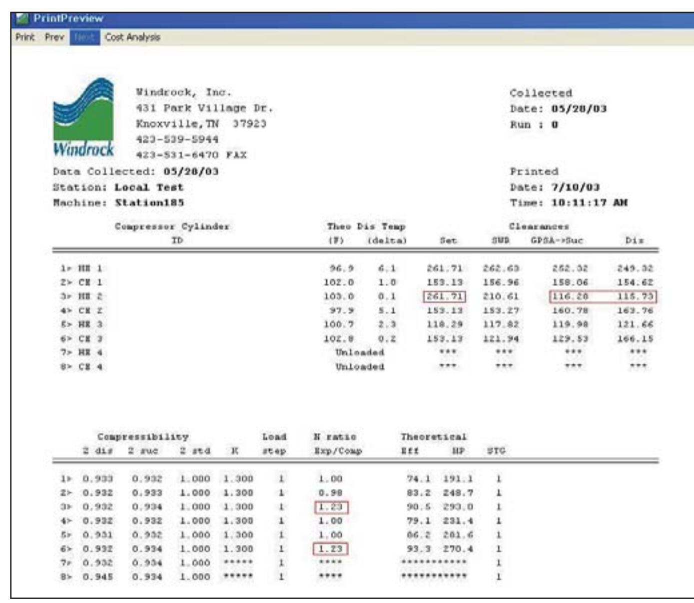


Figure 5. On-Guard® plots of the head end of Cylinder 2 from Unit 15 at Station 120 before and after repair.



PrintPreview

Print Prev Next Cost Analysis

Windrock, Inc.
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Knoxville, TN 37923
423-539-5944
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Collected
Date: 05/28/03
Run : 0

Data Collected: 05/28/03
Station: Local Test
Machine: Station185

Printed
Date: 7/10/03
Time: 10:11:17 AM

Compressor Cylinder ID	Theo Dis Temp (F)	(delta)	Set	SWB	Clearances GPSA->Suc	Dis
1> HE 1	96.9	6.1	261.71	262.63	252.32	249.32
2> CE 1	102.0	1.0	153.13	156.96	158.06	154.62
3> HE 2	103.0	0.1	261.71	210.61	116.28	115.73
4> CE 2	97.9	5.1	153.13	153.27	160.78	163.76
5> HE 3	100.7	2.3	118.29	117.82	119.98	121.66
6> CE 3	102.8	0.2	153.13	121.94	129.53	166.15
7> HE 4	Unloaded		***	***	***	***
8> CE 4	Unloaded		***	***	***	***

	Compressibility Z dis	Z suc	Z std	K	Load step	N ratio Exp/Comp	Theoretical Eff	HP	STG
1>	0.933	0.932	1.000	1.300	1	1.00	74.1	191.1	1
2>	0.932	0.933	1.000	1.300	1	0.98	83.2	248.7	1
3>	0.932	0.934	1.000	1.300	1	1.23	90.5	293.0	1
4>	0.932	0.932	1.000	1.300	1	1.00	79.1	231.4	1
5>	0.931	0.932	1.000	1.300	1	1.00	86.2	281.6	1
6>	0.932	0.934	1.000	1.300	1	1.23	93.3	270.4	1
7>	0.932	0.934	1.000	*****	1	****	***********		1
8>	0.945	0.934	1.000	*****	1	****	***********		1

Figure 6. A portion of the online compressor report for May 28, before repair of the failed unloader.

Acknowledgment

Based on a paper presented at the Gas Machinery Research Council's Gas Machinery Conference, held in Salt Lake City, Utah, October 6-8, 2003.