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A Diagnostic System for Reciprocating Compressors

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A DIAGNOSTIC SYSTEM FOR RECIPROCATING COMPRESSORS

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ABSTRACT

An advanced warning system for maintenance and control of reciprocating compressors is discussed. The compressor is instrumented to measure valve temperatures, interstage pressures and temperatures, rod drops, packing temperature and leakage flow, and numerous other variables. Under control of a microcomputer, a scanner monitors the sensors and updates a database. After a scan, an expert program evaluates the measurements, performs calculations, and checks truth tables to isolate potential problems. Other system features then allow the operator to generate reports, history plots, P-V diagrams, and frameload plots in order to gain further insight and decide on the urgency of a problem. Unscheduled shutdowns can therefore be prevented.

INTRODUCTION

Most rotating equipment is instrumented to provide vibration data for signature analysis. This approach has successfully prevented catastrophic failures. For reciprocating compressors vibration data by itself is insufficient to make a proper diagnosis. Additional information about pressures and temperatures is needed to correlate data and identify problems. Hence, a diagnostic system for a reciprocating compressor may easily include a large number of sensors interfaced to a remote microcomputer. A typical system implemented in a refinery is shown in Figure 1. It consists of:

- Machine mounted sensors.

- A data acquisition system to scan the sensors, digitize the signals, and transmit the data.
- A microcomputer to analyze data and generate control signals.
- Input/output devices such as a CRT terminal, printer, plotter and disk drive.

The specific tasks performed by the diagnostic system are:

- Continuous scanning of all sensors with an updated summary of results on the CRT (Figure 2).
- Reports including raw data and calculated results at regular intervals or on demand (Figure 3).
- Continuous analysis of data by an expert program to identify any problems. Warning messages are displayed if any problem is suspected. Alarm or shutdown signals can be generated.
- Historical data is stored and can be plotted on demand for short or long durations (Figure 4).
- Detailed information on the inner workings of each cylinder can be obtained from cylinder pressure plots (Figure 5).
- Data can be transferred to a host computer or a remote terminal for further analysis.

Figure 6 illustrates the software organization.

SYSTEM FEATURES

The basic advantage of the diagnostic system over the usual instrumentation is that it includes a significant amount of computer power with an expert program that incorporates experience and knowledge of how the compressor should run. A simple example of the advantage of including computing power is the high discharge temperature alarm. Rather than comparing the measured temperature with a setpoint, the diagnostic system measures the pressure ratio and suction temperature and calculates the expected discharge temperature. Discharge valve temperatures are compared to see if a valve is significantly hotter than the rest. Also, the interstage pressures are calculated using clearance volumes at the operating conditions. For a discharge valve to have failed, the discharge temperature measured must be greater than the expected temperature, a valve must be indicated hotter than the others, and also the interstage pressures must indicate that the stage is operating at reduced capacity. Other causes for high discharge temperature could be a high suction temperature due to an intercooler malfunction, a suction valve failure, excessive piston ring leakage, or insufficient cylinder cooling. Each possibility is investigated just like the discharge valve failure. If all these checks are negative, then either the discharge temperature reading is inaccurate or a problem is in its early stages.

The diagnostic system continuously monitors all the running compressors. At any time an operator can interrupt the diagnostic programs and access a menu of options. Typical options available are:

1. Compressor log
2. Quick data listing
3. History plots
4. Cylinder pressure/frame load plots
5. Diagnostic messages
6. Modify setpoints
7. Select print interval
8. Send data to a remote terminal
9. Monitor specific compressors
10. Monitor all running compressors
11. Change compressor displayed at CRT
12. Measure specific channel voltages

Option 1 prints a log for each running compressor (Figure 2). Option 2 prints data for only the compressor displayed at the CRT (Figure 3). One of the running compressors is selected for display at the CRT by default. Option 12 scans a range of channels and prints the voltages measured. This allows checking thermocouples and pressure transducers for proper operation. Option 6 allows the user to change setpoint values such as allowable valve temperature, peak to peak rod drop, bearing temperature, packing reference flow, and packing reference temperature. For rod drop proximators the calibration constants and steady state readings can be modified. Option 8 permits communication of compressor data to a remote terminal via modem for an expert evaluation. In option 4 the cylinder pressure transmitters are scanned at a rate of 360 samples per compressor cycle. A high speed voltmeter and a trigger signal are required for this application.

The system keeps a history of key variables. Recall of this history as plots can be useful in planning maintenance such as replacing a rider band or a packing, and determining causes of failure.

CYLINDER PRESSURE DISPLAYS

Cylinder pressure cards (Figure 5) can be used for periodic checks of performance and can be available at the touch of a key from the diagnostic system. The pressure against volume and pressure against crank angle diagrams provide a direct look at how the compressor is operating internally. They can be compared to diagrams taken when the compressor was running normally to confirm problem diagnosis and to measure the severity of a problem. If transducers are mounted to measure pressure in the cylinder passage, then these traces can be superimposed on the cylinder pressure trace to estimate valve losses, volumetric efficiency, capacity loss, and check for proper valve opening and closing (Figure 7).

The frame load against crank angle diagram (Figure 5) is also available from the diagnostic system. It provides the maximum value of the frame load, which determines the stresses in the compressor components, and the "degrees of reversal" which determine whether the crosshead will perform satisfactorily. If load on the crosshead pin does not reverse each cycle, lubrication of the pin would be lost and the bearing will fail rapidly. These two values should be checked for all cylinders if the compressor is running under abnormal conditions.

FLEXIBILITY

The diagnostic system can be configured to meet a variety of customer's needs (Table 1). A simple system might include a few sensors and use a small computer with limited memory and a simple display device. A large system might monitor more than one compressor, use several hundred sensors, and the computer could have peripherals including a hard disk, graphics CRT, printer, plotter, and interface to a host computer.

OPERATION

With the compressor running normally, the data displayed on the CRT will be monitored occasionally to ensure that the system is working correctly. The log sheets that are printed regularly will be collected and filed for reference.

If the diagnostic system detects a problem, an alarm will be generated, and the system display should be examined. The diagnostic message will indicate the most accurate interpretation it can make of the data.

In many cases, an indication of failure will be given before the cause is obvious. As the failure progresses, the diagnosis will become more definite as several clues indicate the same problem.

Once an incipient failure is detected, the maintenance people can use the menu of options discussed earlier to gain a better understanding of the problem and then plan the corrective action.

If an unusual problem occurs, data can be transmitted to the factory for an opinion. This interaction can quickly resolve a potential field problem.

CONCLUSION

Expert diagnostic systems are now available to monitor reciprocating compressors and prevent unscheduled shutdowns. These systems are customized for the specific application and needs of the user. Depending on the number of variables monitored, the diagnostic system can be expanded from performing simple data logging tasks to becoming a preventative maintenance tool. The key part of any such system is the specialized software to predict compressor problems from numerous measurements. As experience is gained, and benefits accrue, these diagnostic systems will become a normal part of any reciprocating compressor installation.

Essential for Minimum System

- Transducers for suction and discharge pressure and temperature of each stage.
- A/D scanning system
- Microcomputer
- Printer or CRT

Optional

- Transducers for:

Valve Temperatures	Bearing Temperatures
Piston Rod Drop	Oil Pressure or Temperature
Packing Temperature	Packing Vent Flow
Clearance Pocket or Unloader Position	Vibration
Motor Temperature	Cooling Water Temperatures
Speed	Capacity
Motor Horsepower	Filter Pressure Drop

- Cylinder Pressure Measurement System
- Graphics Display
- Interface to Host Computer
- Modem for Remote Access

TABLE 1 - DIAGNOSTIC SYSTEM COMPONENTS

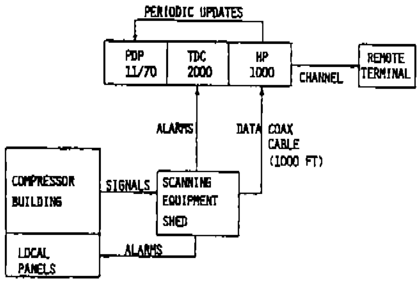


FIGURE 1 GULF EDMONTON SYSTEM

WORTHINGTON DIAGNOSTIC LOG

COMPRESSOR NO.			52K-2B			
TIME			8:53 PM TUE, 18 OCT, 1983			
BEARING TEMP. (F)			118 122 121 121 123			
CONTROL STEP			3			
STAGE			1	2	3	4
PISTON ROD RUN OUT (MIL)	PEAK TO PEAK		5	10	4	12
	AVERAGE		5	14	6	9
ROD PACKING TEMP (F)			138	131	148	178
PACKING VENT FLOW (%)			0	0	0	0
MAXIMUM SUCTION VALVE TEMPERATURE	H.E.	VALVE NO.	1	2	2	1
		TEMP. (F)	96	76	76	83
	C.E.	VALVE NO.	3	2	2	1
		TEMP. (F)	93	76	76	82
MAXIMUM DISCHARGE VALVE TEMPERATURE	H.E.	VALVE NO.	3	2	2	1
		TEMP. (F)	182	149	198	245
	C.E.	VALVE NO.	2	2	1	1
		TEMP. (F)	178	149	282	242
SUCTION TEMP. (F)			92	75	78	82
SUCTION PRESSURE (PSIA)	MEASURED		257	406	596	1181
	CALCULATED			395	596	1140
DISCHARGE TEMP. (F)	MEASURED		188	152	198	243
	CALCULATED		181	0	196	246
DISCHARGE PRESSURE (PSIA)	MEASURED		405	0	1191	2671
	CALCULATED		408	615	1184	
REMARK						

FIGURE 2 COMPRESSOR LOG

Worthington COMPRESSOR UNIT 53K-1B

CYLINDER	1	2
ROD RUNOUT (MIL)	7	5
SUCTION TEMP (F)	67	81
DISCHARGE TEMP (F)	175	212
DISCHARGE TEMP CALCULATED	185	227
SUCTION PRESSURE (PSIA)	113	220
DISCHARGE PRESSURE (PSIA)	237	508
DISCHARGE PRESSURE (CALC)	228	508
PACKING TEMPERATURE (F)	189	180
PACKING FLOW (%)	6	0

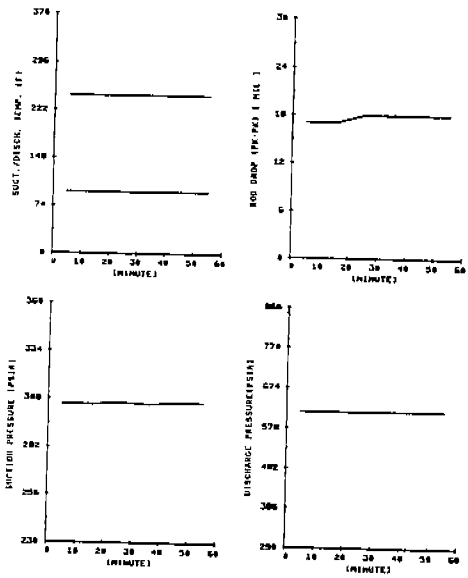
VALVE TEMPERATURES

CYLINDER	VALVE NO.	SUCTION VALVES		DISCHARGE VALVES	
		HE	CE	HE	CE
1	1	67	63	173	171
1	2	63	61	75	171
1	3	66	65	174	172
2	1	84	83	215	208
2	2	85	82	214	210
2	3	0	83	215	0

BEARING TEMPERATURES

OUTBOARD	119
MOTOR END	122
PUMP END	117

FIGURE 3 QUICK DATA LISTING



COMPRESSOR 52K-2A STAGE 1 LAST 01 HOUR DATA

6:20 AM THU., 21 JUNE, 1984

FIGURE 4 HISTORY PLOTS

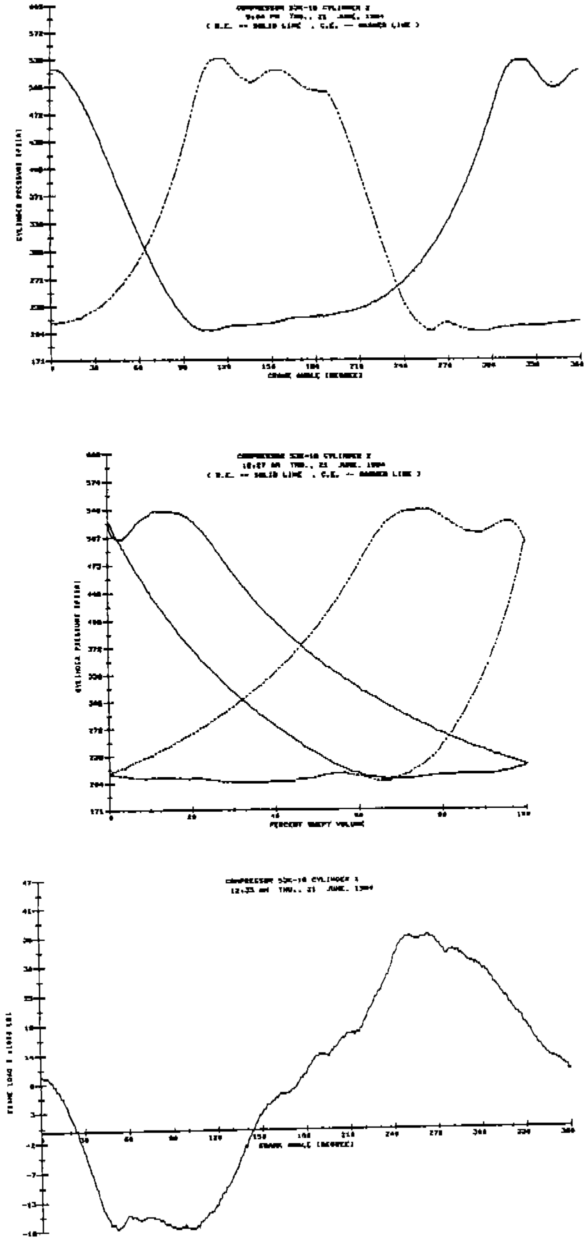


FIGURE 5 CYLINDER PRESSURE PLOTS

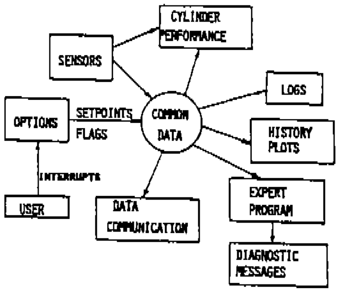


FIGURE 6 PROGRAM ORGANIZATION

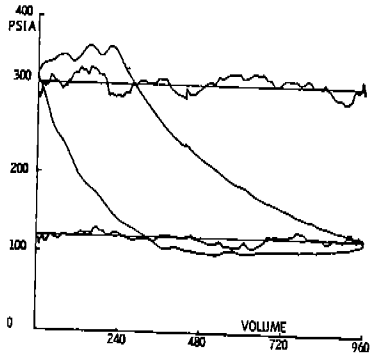


FIGURE 7 ESTIMATE CYLINDER PERFORMANCE