Application Note

On-line Reciprocating Compressor Monitoring Instrumentation

Introduction

This application note discusses a number of approaches to the question of instrumentation needed to acquire and process measurements for condition monitoring of reciprocating compressors. The appropriate measurements and sensors are discussed in separate application notes. The retrofit of existing machines offers the greatest challenge and this case forms the basis of the application. New machines can also be considered. A typical machine is illustrated in **fig. 1**.

The three main components of any monitoring system are:

- Sensors
- Data acquisition system
- Operator interface

Figure 1. Typical machine.

Sensors

Fig. 2 shows the possible sensor measurements that may likely be taken in a reciprocating compressor application, for each cylinder. On some machines this complexity will be justified, on others it will not. The decision on which measurement to take is a balance between common problems experienced in the past, access to transducer locations and, of course, available financial budget. At one end of the range we may have a system consisting only of a single transmitter and accelerometer measuring frame vibration, and at the other a system with over 70 measurements.

Data acquisition system

There are a number of choices in the approach to the acquisition of data from the installed sensors on these machines, and the best route is usually determined by the following variables:

- Distributed or centralized system
- Number of machines and channels
- Hazardous area restrictions
- Operator interface
- Complex analysis

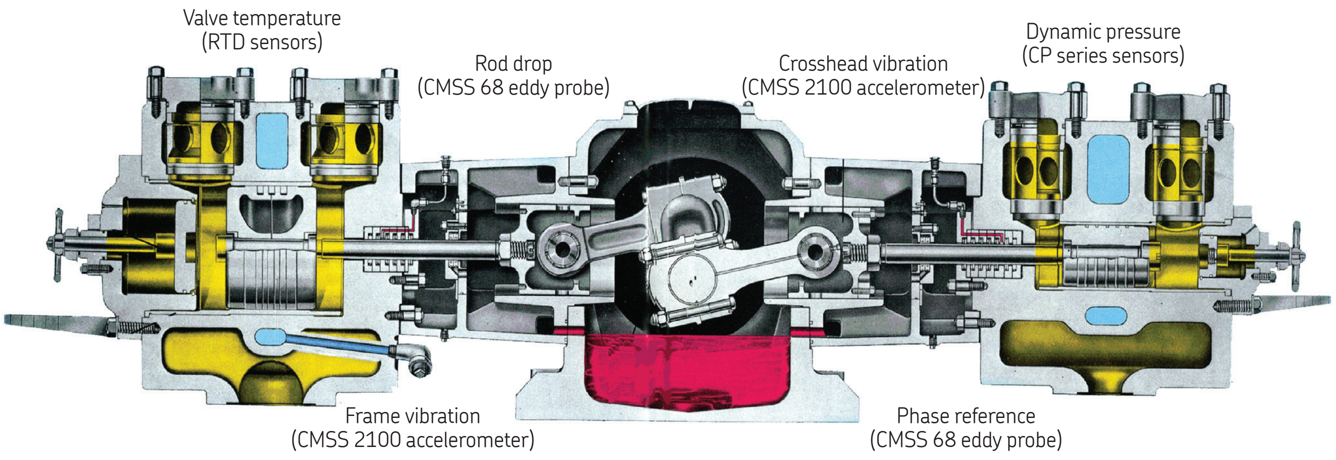


Figure 2. Possible measurements.

Distributed system

This approach is based upon the CMSS 500 series transmitter (→ **fig. 3**) and is illustrated in **fig. 4**. In a distributed system, we have multiple machines spread across a plant with only a small number of sensors per machine.

There is a single transmitter for each sensor type, vibration, rod drop or temperature. The transmitter provides a 4 to 20 mA output, which is input into a local PLC, which may already exist, as part of the distributed control system (DCS).

The key consideration here is the cost of field cabling. Costly dynamic signal cable (required for vibration signals) is used over only a short run from transducer to CMSS 500 transmitter located near the machine. From the transmitter, a short run of 4 to 20 mA signal cable is used to some kind of nearby PLC or analog/digital converter. The signals are converted in these devices to digital protocols (e.g., modbus). Then the longest cable run, to the control room, is by a simple, inexpensive, twisted-pair serial cable. This reduces installation costs significantly and eliminates the risk of interference to the vibration signals over long distances.

Figure 3. The CMCP 530 transmitter.

Centralized system

This approach is based upon the VM600 Machinery Protection System (→ **fig. 5**). In a centralized system, we have multiple machines concentrated in a single plant area, with a large number of sensors per machine.

Each monitor measures multiple channels of vibration, rod drop or temperature at a single location. The monitors are physically located in an instrument cabinet or panel, in some type of interface building with other DCS equipment. Such buildings are usually environmentally controlled, removing the monitoring function from exposure to conditions like excessive heat or saltwater corrosion.

Each monitor will provide a single interface to all the sensors, providing them with power and necessary signal conditioning (e.g., filtering).

In addition, the monitor can be easily located near other instruments or computers, which may provide further analysis capability.

The drawback is the dynamic signal cabling, with appropriate shielding, must be run from machine to monitor for every channel, typically in a multi-pair cable.

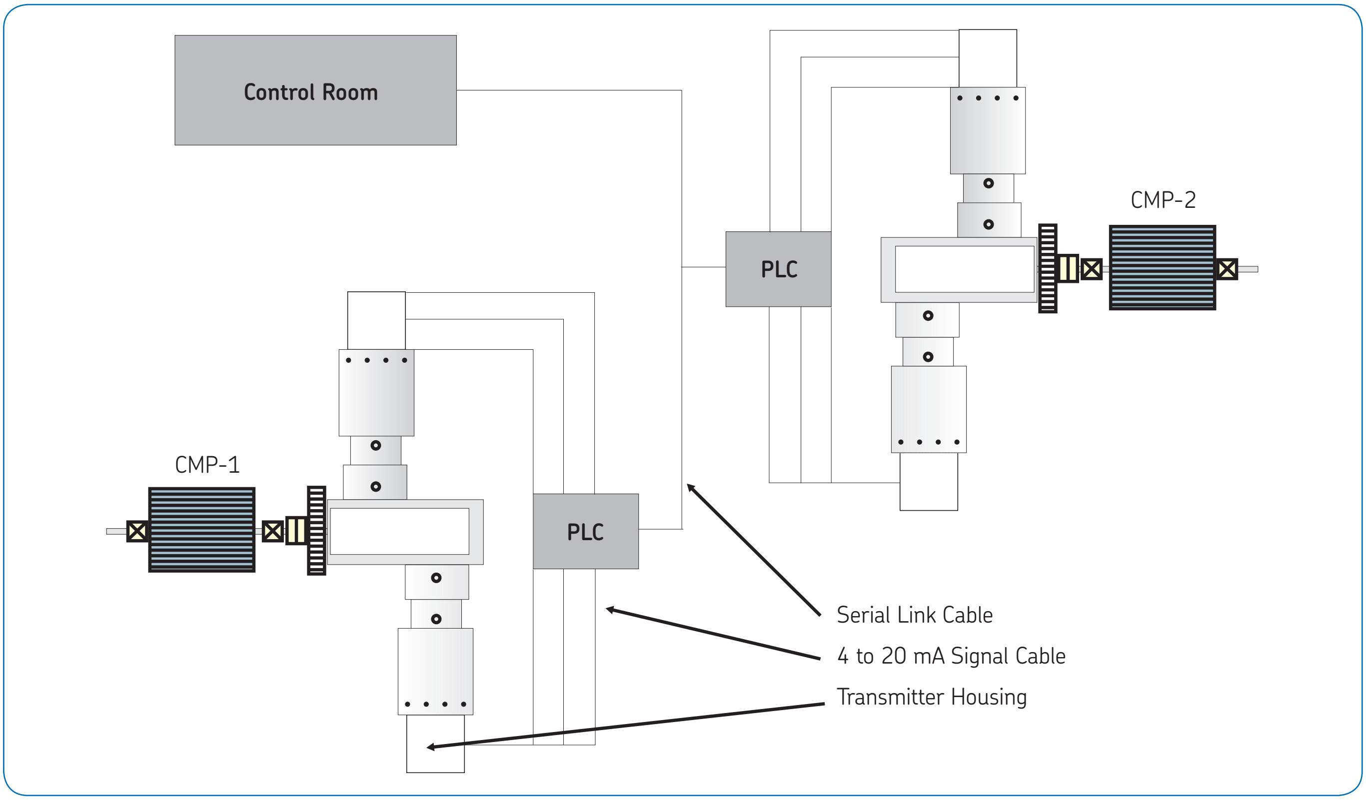


Figure 4. Distributed system.

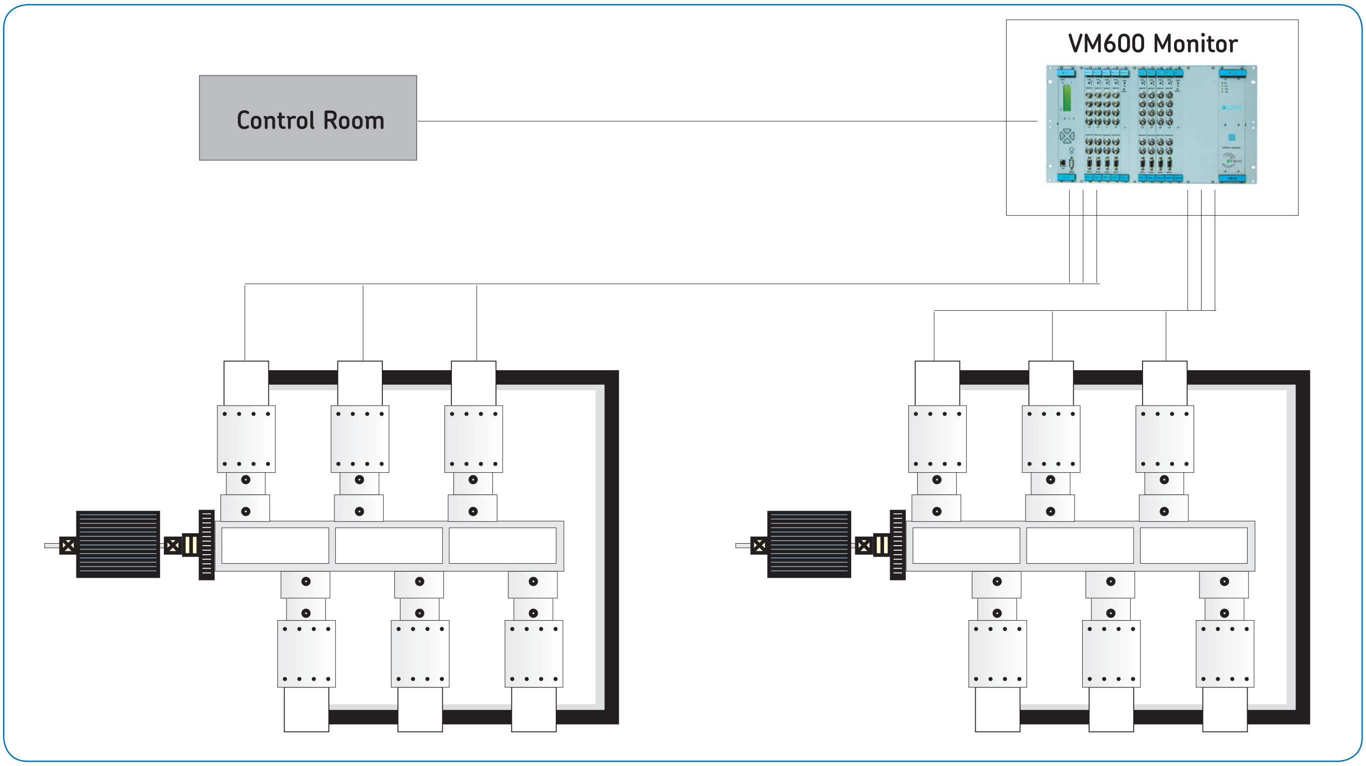


Figure 5. Centralized system.

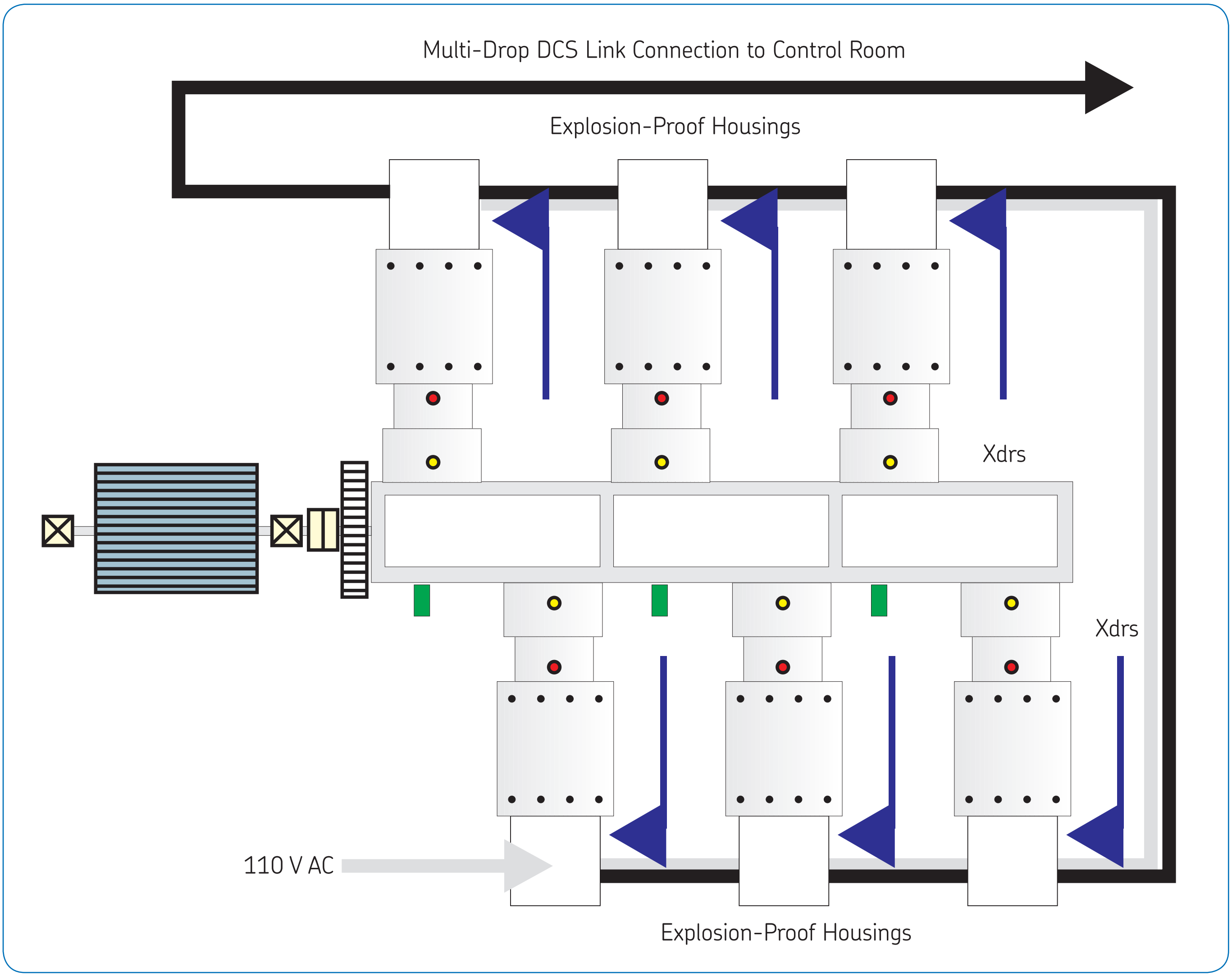


Figure 6. Distributed system in Class I, Division 1 area.

Number of machines and channels

The use of transmitter devices generally is most cost effective when there are only one or two measurements per cylinder, on two or three cylinder machines. In this case, the cost of the acquisition hardware is lower per channel than a centralized approach, and the installation costs are lower.

The use of centralized monitor devices are more cost effective when there are eight or more measurements per cylinder, on four or six cylinder machines, and signal cabling already exists (perhaps from an older system) or cabling is being laid as part of a larger instrumentation project. In this case, the cost of the acquisition hardware is lower per channel than transmitters, and the installation costs are included in a larger scope development.

Hazardous area restrictions

Many compressors are used in the oil, gas, refining and petrochemical sectors, and as such are compressing hazardous (inflammable) gases.

This must be considered when choosing an instrument approach. The first consideration is which classification code is being used by the application site:

- North American “Division” Code
- European CENELEC (IEC) Code

The “Division” code permits use of “explosion-proof” housings to prevent a malfunctioning instrument from causing a gas explosion. An explosion-proof housing is a very sturdy metal box, with specially designed inlets/outlets. Inflammable gas is permitted to ingress into the enclosure. If an instrument malfunctions and a spark is produced, then the gas within the enclosure will ignite, but the explosion is contained within the enclosure, and no ignition mechanism escapes into the flammable atmosphere outside.

Fig. 6 shows an explosion-proof application to Class I, Division I. In this application, the channel count was high, but no existing field cabling was present, thus a transmitter based system was used. Each cylinder has an explosion-proof housing rated to Class I, Division I, gas Groups B, C and D.

Each housing contains transmitters and analog/digital converters, which are connected by multi-drop link to the control room by a single cable.

In contrast, the IEC code requires all instruments in the equivalent hazardous area to be approved Intrinsically Safe (IS) and certified as such. Intrinsic safety means each instrument, or other device, located in the hazardous area has, by design, insufficient electrical energy to produce a spark that can ignite the rated gas in the event of an instrument fault (or faults).

Intrinsically safe sensors are common, however, most vibration monitor devices do not have an Ex i rating owing to their electrical design and complexity.

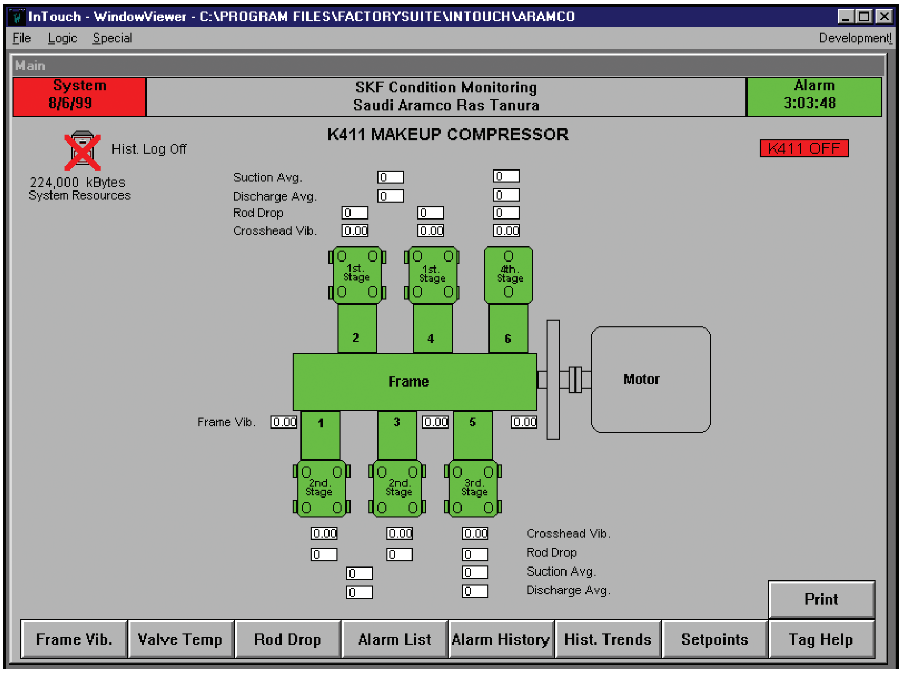


Figure 7. Main screen.

In an European CENELEC intrinsically safe application, the approach would be to use a centralized system, where the monitor system is located in a "safe" area where no inflammable gases are present. The monitor is typically isolated from its sensor devices (located in the hazardous area) by means of safety barriers, one per channel.

Operator interface

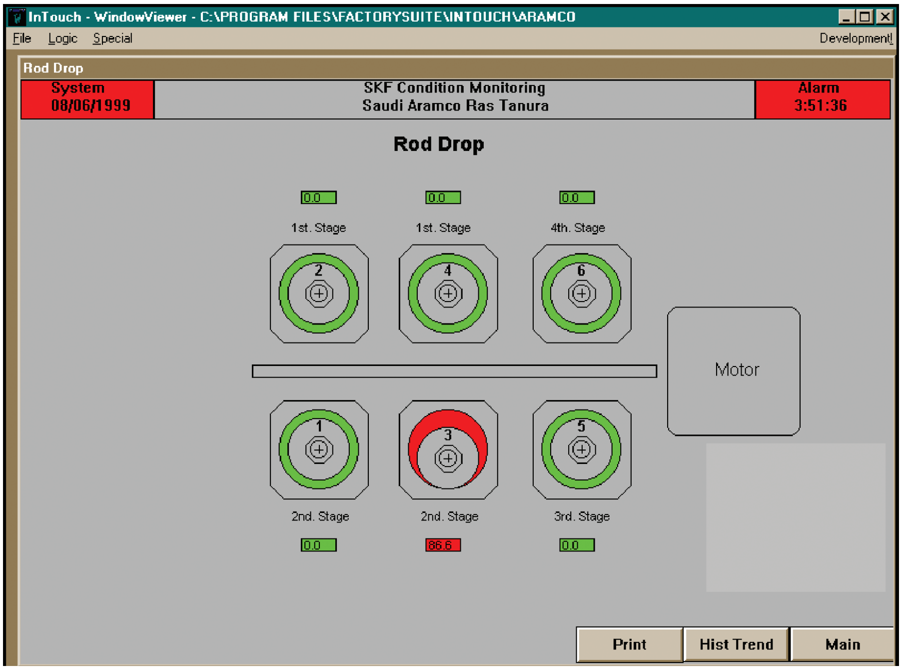
Whether a distributed or centralized architecture is employed, the interface with the system for the operators can be the same. This human machine interface (HMI) should have a minimum set of features:

- Machine graphic
- Live display update
- Historical trending
- Event log

The data acquired by the CMCP 500 series transmitter system can be made available in a serial modbus protocol by means of a Six-Net converter unit. The data acquired by VM600 monitors can be made available in a serial modbus protocol by means of a CPU-M interface. Once in this serial format, the data can be easily input into a PC-based human machine interface.

Figs. 7 through **9** show screens in the FactorySuite 2000 Package from Wonderware, but similar results may be achieved by any number of commercially available HMI packages, including the DCS itself. In **fig. 7**, we see a main interface screen for a compressor. The "machine level" channel values are updated live. Each part of the machine has a dynamic color-coded alarm signal. If, for example, a rod drop on cylinder 1 moves into an "alert" condition, then cylinder 1 on the main screen will begin flashing yellow, and flashing red when a "danger" condition exists. By clicking onto the **Rod Drop** button, we may proceed to the *Rod Drop screen* (→ **fig. 8**), which clearly illustrates the concept of rod drop to the operator, with a live display.

Such a human machine interface should also have the ability to perform calculations on the measured variables.


InTouch - WindowViewer - C:\PROGRAM FILES\FACTORYSUITE\INTOUCH\ARAMCO

Rod Drop

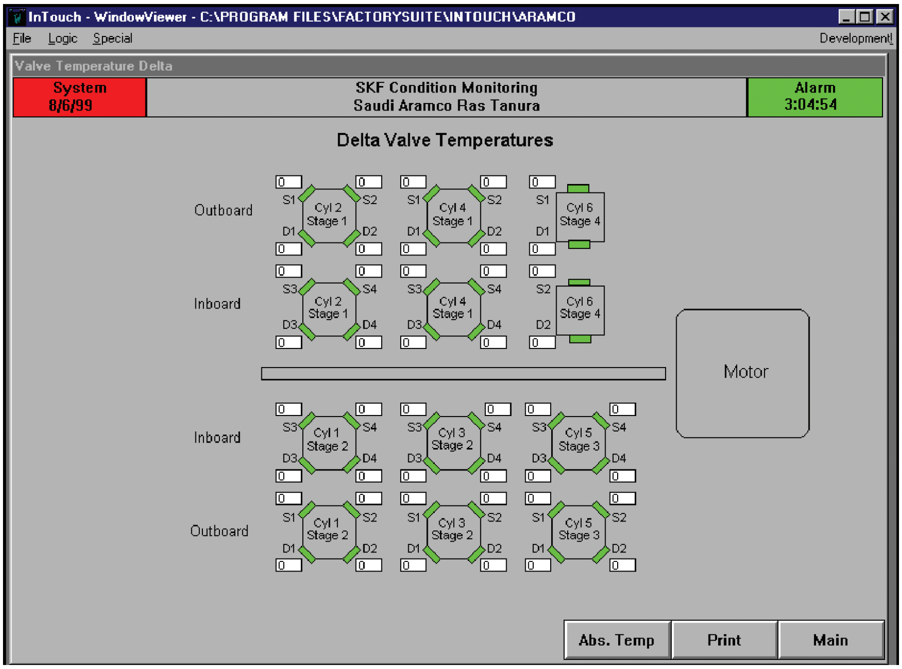
System 08/06/1999

SKF Condition Monitoring
Saudi Aramco Ras Tanura

Alarm 3:51:36

Rod Drop

Figure 8. Rod Drop screen.


InTouch - WindowViewer - C:\PROGRAM FILES\FACTORYSUITE\INTOUCH\ARAMCO

Valve Temperature Delta

System 8/6/99

SKF Condition Monitoring
Saudi Aramco Ras Tanura

Alarm 3:04:54

Delta Valve Temperatures

Figure 9. Delta Temperatures screen.

Fig. 9 shows a *Delta Temperatures screen*, where the temperature value of each valve is subtracted from the mean temperature of all valves on that suction or discharge stage, thereby quickly identifying the "odd man out". This is particularly effective when it is realized that the most common problems are with valves.

The key to this interface is to provide operations staff with timely and accurate machine condition information they can easily understand, without the confusion of complex analysis plots. Operators control the destiny of the machine; it is they who can take immediate action if, for example, the process balance of the cylinders is creating excessive vibration.

Complex analysis

The previous example uses a monitoring system that is practical and effective. Such an approach can be expanded to add more complexity, provided there are staff available to understand such complexity. There are two main analyses that are commonly applied:

- Crosshead vibration signal analysis
- Pressure volume analysis (PV)

Crosshead vibration analysis

This is illustrated in **fig. 11** with Prognost software and involves breaking down the dynamic vibration signals into constituent components through a single cycle. This requires a phase marker in order to determine the crank angle at any point in time. Fast Fourier Transforms (FFTs) are also calculated, but are notoriously difficult to analyze on reciprocating machines, owing to the complexity of vibration frequencies inherent in the design of the machine.

Pressure/Volume analysis

Additional insight to cylinder behavior may be viewed by running a pressure/volume curve (or pressure/volume) diagram (→ **fig. 10**), again from Prognost. Volume is determined by the stroke position, and cylinder pressure is obtained with a dynamic pressure sensor. This gives you an overview of the whole expansion/compression cycle. Problems such as valve or piston ring chatter can be detected, and the performance of the compression cycle itself optimized.

Some practical factors need to be considered when considering to implement complex analysis.

Firstly, retrofitting of such tachometers is sometimes difficult.

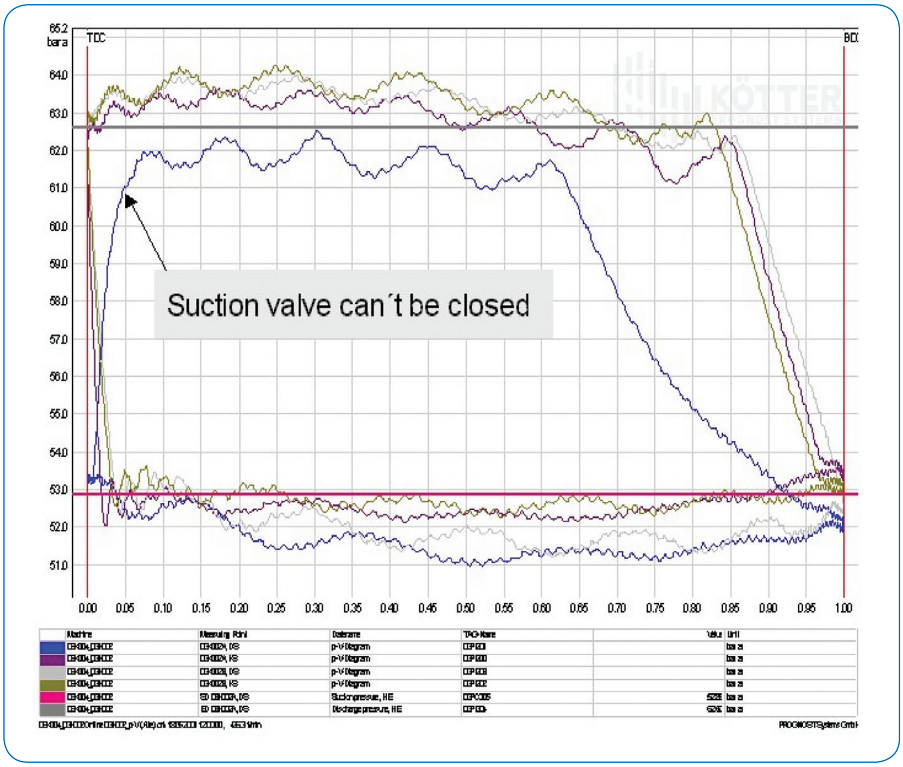


Figure 10. Pressure/Volume (PV) of the expansion-compression cycle.

Figure 11. Vibration during a single cycle.

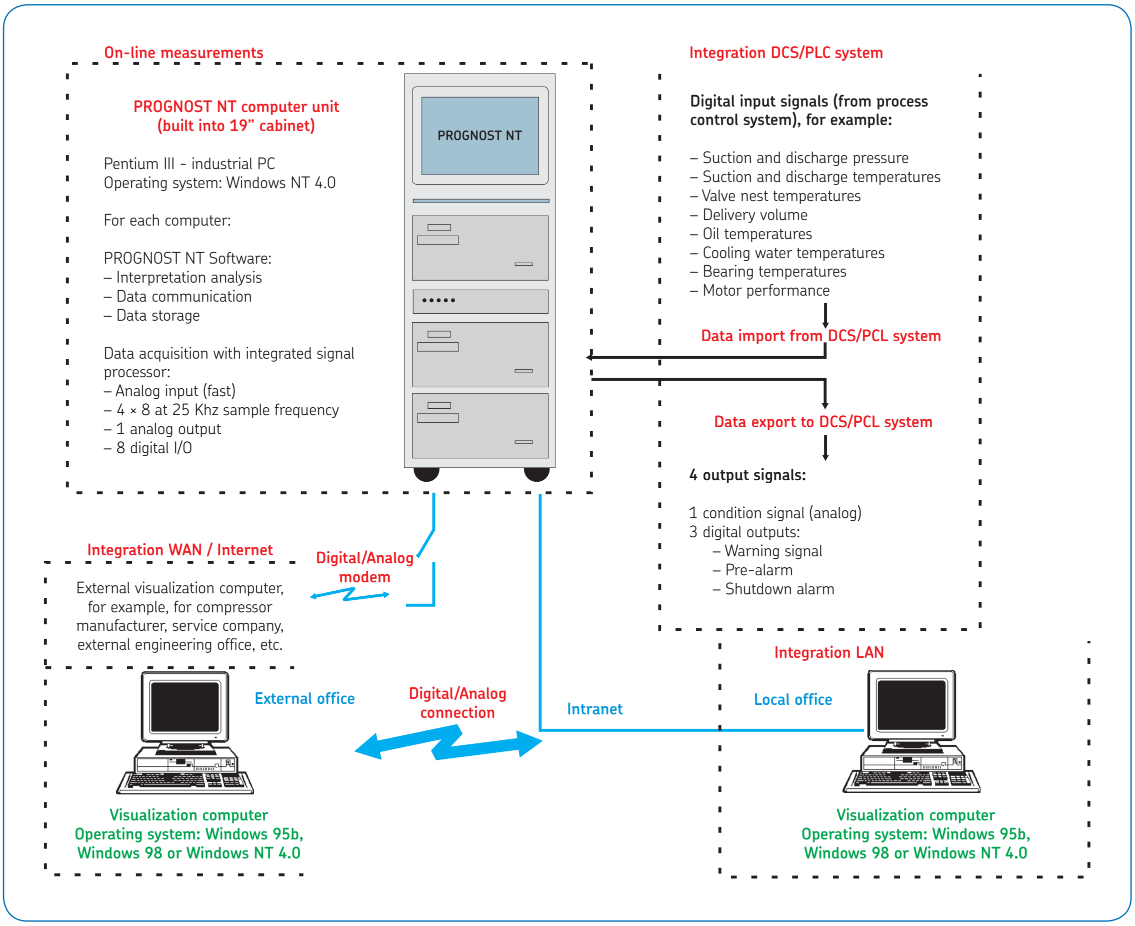


Figure 12. Complex system hardware – Prognost.

Secondly, for pressure volume, a direct measurement of cylinder pressure is required. This can only be achieved if there is a suitable tapping in the cylinder to fit a sensor. If one is present, then a pressure transducer may be fitted.

The dynamic cycling this pressure sensor will experience will be significant, perhaps over 2 000 PSI many times per second, and this places great strain on the sensor, to the extent where life is shortened.

Thirdly, in order to capture data fast enough to plot data over a single stroke, over many channels in parallel, a device with an acquisition speed in excess of 20 kHz per channel is required. Such acquisition equipment is most suited to a centralized, permanent installation, frequently in parallel with a VM600 protection system. **Fig. 12** shows a Prognost system installation, which may be networked to provide information plant-wide.

Please contact:

SKF USA Inc.
Condition Monitoring Center – San Diego
5271 Viewridge Court · San Diego, California 92123 USA
Tel: +1 858-496-3400 · Fax: +1 858 496-3531

Web: www.skf.com/cm

PUB CM3080 EN · April 2011