Technical Paper

# New Concepts in Machinery Protection and Monitoring

## Abstract

Protection systems, in general, are based on analog designs and require expensive modifications and component changes to provide the level of protection your modern machinery requires to operate profitably.

Recent advances in the process control field have led to the integration of digital electronics with host computers to control the processes these machines handle. These new microprocessor based protection/monitoring systems will revolutionize the interaction between the maintenance and process activities. This paper describes many of the advantages and new monitoring concepts that modern digital machinery protection can offer.

## Introduction

The rapid emergence of microprocessors and computers in the control room are creating a new direction in the way rotating equipment is being monitored for its operating conditions. These mini and personal computers develop charts and reports; collect, process and store months of data and, in some cases, provide various color graphics and display screens to provide precise, up-to-the minute status of your process and machines' condition.

These "new concepts" in machinery condition monitoring using microprocessors are revitalizing the somewhat routine world of machinery monitoring. After all, microprocessors have been controlling your critical processes for over 15 years. It is now time for machinery monitoring to be brought into the present.

But before we get ourselves lost among the trees, let us take a step back to look at the forest.

Let us first determine why we would choose to monitor the health of a piece of rotating equipment. Two reasons quickly come to mind.


*Fig. 1. The SKF M800A programmable machinery monitoring and protection system.*

# Failure prediction

The first reason is to gather the information necessary to identify an impending mechanical failure and hopefully remove it in time from service, or if not, to conduct a postmortem analysis on it.

# Machinery protection

The second reason, but perhaps most important, is to protect the machine from catastrophic failure. Protecting a machine from catastrophic failure means to isolate the mechanical failure to the one or two minor components that fail, while protecting the rest of the machine by safely and automatically removing it from service.

A minor mechanical failure depending on the failed component usually results in from one to two days of repair time at a cost of between $500 to $10 000 in material and labor costs. However, if that same machine undergoes a catastrophic failure, the process down time can extend into several weeks, with the repair costs approaching the original cost of the machine.

Can we or should we trust our critical equipment to a single host mini- or micro-computer that is designed as a tool to manipulate and massage data? Machinery bone yards are beginning to fill with machines that were protected (or should I say monitored) by a "computerized system".

# Why protection pays

Let us examine an example presented by John Kemper, Philadelphia Electric, in his keynote address at EPRI's Third Conference on "Incipient Failure Detection". In his address, Mr. Kemper cited a catastrophic failure of a fan in one of their power plants. Although their computerized monitoring system had detected an impending failure, no limits were exceeded and plans were being made to correct the problem. Postmortem estimates projected that the routine repair of the initial component failure would have taken three days to repair, at a total cost of $96 000. The repair of the catastrophic failure took 14 days and cost close to $420 000! Although this illustrates an extreme case, it also emphasizes the value and reliance placed on a machinery protection system. This $320 000 excess expense was more than enough to totally protect **every** piece of major rotating equipment on the unit.

Most experienced machinery engineers can readily cite numerous machinery failures occurring in spite of on-line condition monitoring. The warnings and alarms are ignored by normally conscientious operators, because they do not trust the alarm or expected a bad transducer. In fact, as Robert J. Rosauer, Supervisor of Electrical Engineering, Woodward Governor Company, states in the Turbomachinery International magazine, "Input/Output (I/O) signal faults are a common cause of control-system errors. The majority of all faults are attributable to either the I/O devices themselves, their wiring or their signal conversions".

# Protection standards

The above examples help explain the value and need for standards such as API 670 and API 678. After many years of successes and failures, these standards were generated by machinery engineers "looking for a better way" to monitor and protect their critical rotating equipment. As the next generation of vibration monitoring systems begin to emerge, let us not forget the teaching of these time-proven standards.

As John Reasons points out in Power magazine, "The worst vibration monitoring system is one that fails to warn of a machine that's in trouble. Almost as bad is a vibration monitoring system that shuts down a good machine".

API standards were developed with certain key reliability features incorporated in them to ensure a warning is generated when a machine is in trouble or that it does not cause a false shut down. Such features as I/O signal fault checks, dual channel voting, relay time delays, individual channel limits and detection with continuous analog output are some of the features that separate a **protection** system from a **monitoring** system.

Considering that the function of a protection system is to protect the machine, can we or should we trust these critical decisions to microprocessors? The overwhelming acceptance of microprocessors in all other areas of instrument and control systems suggest that we should. Their rapid growth in these areas clearly shows that digital techniques are displacing analog systems because of their superiority and cost benefits. Let us first examine some of the advantages of today's proven microprocessor technology.

## Increased reliability

Single-chip micro-controllers use internal addresses and data buses to reduce the number of external connections that can fail. Additionally, these devices are highly reliable and seldom fail because they have no moving parts. Most microprocessors contain watchdog timers to conduct self-checks and monitor the computational integrity of the device. Digital comparisons are not subject to drift and do not require periodic recalibration or checks.

## Increased flexibility

Analog systems require specific component selection and arrangement to perform its design function. Any change in the systems' functional requirement, regardless of how trivial, means component replacement or adjustment and recalibration. Digital systems, however, can be quickly and easily programmed to accommodate the small but expensive changing system requirements. This enables one or two simple system designs to satisfy many functional requirements.

## Reduced costs

Digital systems allow for better and faster manipulation and noise-free transmission of data using more modern and efficient techniques than analog systems. This results in reduced wiring and installation costs, which in many cases far exceed the initial cost of the system.

A digital system's programmability allows the user to easily tailor the system to the unique requirements of a particular application. This feature greatly reduces the amount of engineering time and costs associated with the project. Better and faster digital data manipulation allows the sharing of combined functions, such as comparator and alarm circuits, eliminating the duplication of these functions in every circuit. Digital systems lend themselves nicely to computer aided calibration, checkout and functional tests, providing a faster and more comprehensive check of the entire system, at a lower cost.

After reviewing a few advantages of digital technology, let us look at a few of the methods that are taking advantage of this emerging technology. API standards and good engineering practices have already established the difference between a **protection** system and non-critical machinery **monitoring** systems. Let us examine where these new emerging systems should reside.

# First generation plant monitoring systems

One approach distributes microprocessor controller multiplexers throughout a plant and routes the raw vibration signals back to a central, commercially available PC or processor with signal conditioning capability. The host system processes, compares, manipulates and stores the data for later reference.

These systems provide sequential monitoring of a large population of transducers at a lower cost per installed channel, and are usually capable of scanning and storing data from hundreds of points. But, because the host processor must process the signal, comparing it to pre-determined limits and handling the data storage, each point takes several seconds to scan. An average machine's monitoring system (13 points) costs about $1 000 to $1 500 per channel (typically higher than API systems) and monitors each point approximately every one and a half to two minutes.

Adding another machine may reduce this cost to between $700 and $1 000 per channel, but now each channel is monitored every three or four minutes. This is far more frequent than the biweekly or monthly readings that are currently being gathered with portable data collection systems, but will it protect a machine from a catastrophic failure? We must remind ourselves how only a few seconds allows a machine to destroy itself once a component fails.

This approach provides the user with important and relatively current machinery condition information, and will provide a warning of impending mechanical failure, but will not serve nor should it be used as a protection system.

This system provides low-cost monitoring for a large number of channels, but as additional channels are added, the length of time between scans increases, and the amount of protection decreases.

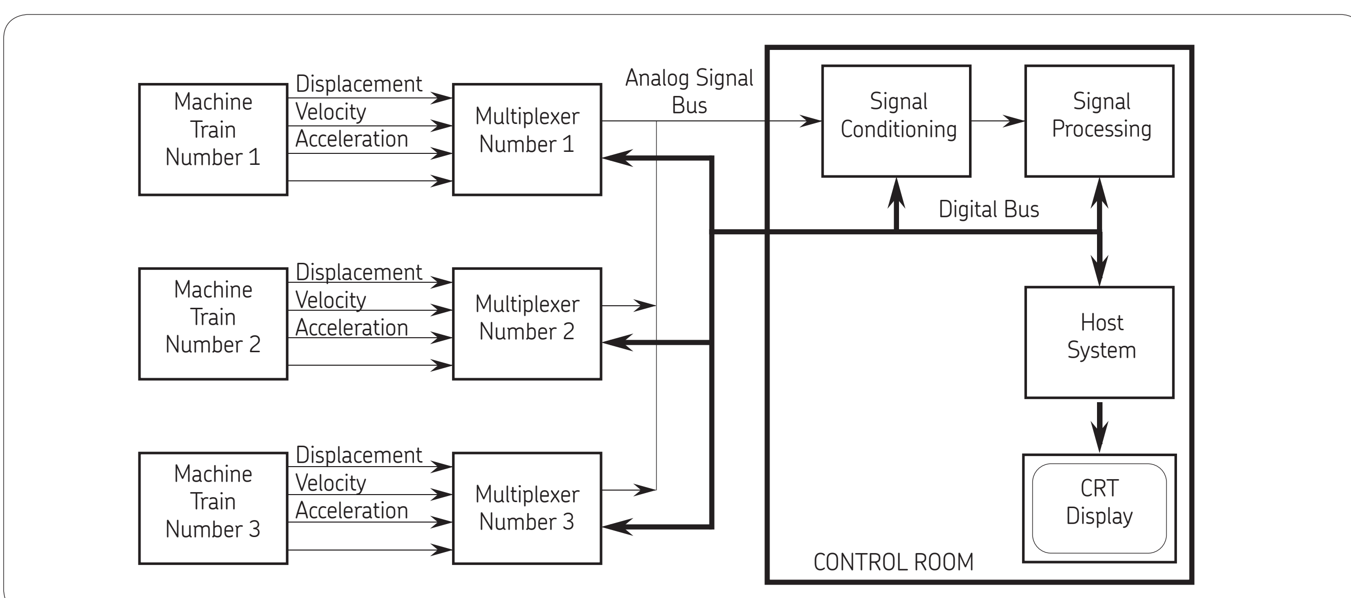


*Fig. 2. The first generation approach requires running both an analog bus and a control bus (digital) back to the control room. A single host system sequentially monitors each transducer.*

# Second generation monitoring

A second type of system directly incorporates a microprocessor into an independent stand-alone monitoring system, to control the alarming and relay functions of the channels under its control. These systems provide continuous analog signal conditioning cards that accept the signals from the various transducers that make the critical measurements.

The single microprocessor scans the conditioned output from the various analog cards and compares them to predetermined levels. Each system scans between 15 to 64 channels from the conditioning cards that have one, two or four channels on each card. However, these cards are of an analog design and they require factory configuration, and all channels must be identical or require expensive modification. Additionally, any special filtering, integration, transducer sensitivity, scale range or detection type must be predetermined.

One system even offers over 50 various analog cards to monitor virtually any parameter desired. Since each system is independent of the others and can accept a large number of channels, signals are routed to the central system. Any savings generated in the lower cost of the system is transferred to the cost of installation. The cost of the bare system (without conditioning cards) is usually high because of the many functions the single processor is attempting to perform. This makes it an economical system only with a large grouping of similar channels. The cost of a 30 channel system typically ranges from $500 to $750 per channel. But, since the average number of monitored channels is 13 per machine train, the cost of a separate system per machine may approach $1 000 to $1 500 per channel (more expensive than API type analog monitoring).

The systems usually monitor each channel at least once per second. They rely on a single processor to orchestrate the entire system, which may or may not identify a component failure in time to isolate it and prevent further damage to the machine. Although usually reliable, a failure or a simple hang-up of the processor or system results in your entire machinery train or trains being totally unprotected. If this occurs at a time of high activity (during a machinery component failure), will it protect your machine? Although these systems have incorporated some of the reliability features of the API standards, can they reliably protect a failing machine?

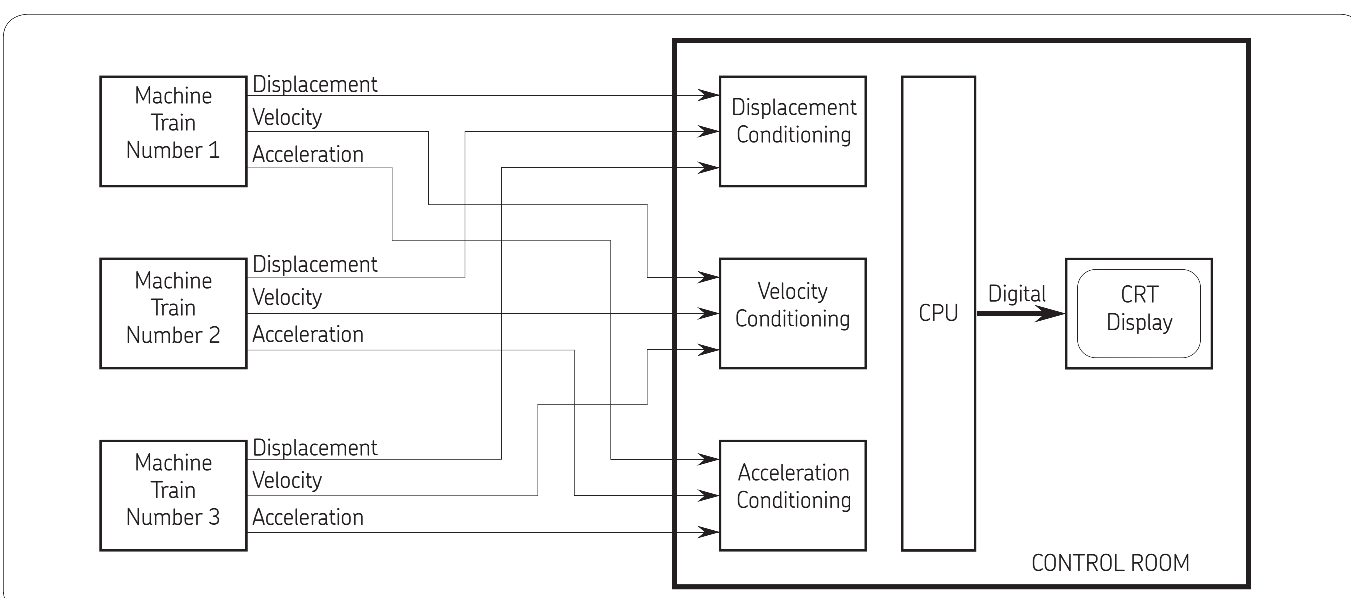


*Fig. 3. The second generation approach requires running all analog signals to individual conditioning cards. The single CPU controls the entire system.*

# Serial communications adapters

The third approach attaches a digital conversion package to previously installed or new analog systems. These serial communications adapters provide a bridge between analog machine protection and computer-based monitoring and analysis systems. Although they provide some of the information necessary to evaluate a machine's mechanical condition, does this help to eliminate any of the challenges facing plant engineers in today's highly changing plants and process? Piggy-backing serial communications on analog monitors adds to the system costs without gaining the full programmability benefits of microprocessors. The analog monitor will have high maintenance costs due to their age and contain components that are obsolete or hard to find. Although these components may be available now, consider the availability of these components in five or ten years. Closely examine the instruments that were installed in your plants 20 years ago – can you reliably operate them for another five or ten years?

Adding the digital conversion kits to analog systems that were not designed for it may be appropriate for existing installations to preserve the machine protection investment, but it will be expensive. Installing a new system requires the high initial cost of the analog system ($750 to $1 000 per channel) plus an almost equal cost of the digital conversion kit.

Among the challenges facing today's plant engineers is how to get a handle on inventory costs. One of the key drawbacks to the above monitoring systems is the large variety of monitors required to effectively protect your machine. A monitor may be of a similar type, but it may differ in the scale required, the type of detection, the voting logic, the trip relay delay and a whole matrix of other functions. These changes add to the cost of configuring, buying, installing and maintaining a machinery monitoring/protection system.

Additionally, the user is forced to choose between modifying the new analog system to interface with the installed, non-standard transducers or to accept the cost of replacing all of these non-standard transducers as a cost factor of the new system. Selecting the first choice adds costs to the system both up front, with expensive modifications, and throughout the monitoring systems life because of the higher replacement costs of non-standard or obsolete transducers. The second choice adds an unnecessary cost up front because the transducers may have many years of existing life.

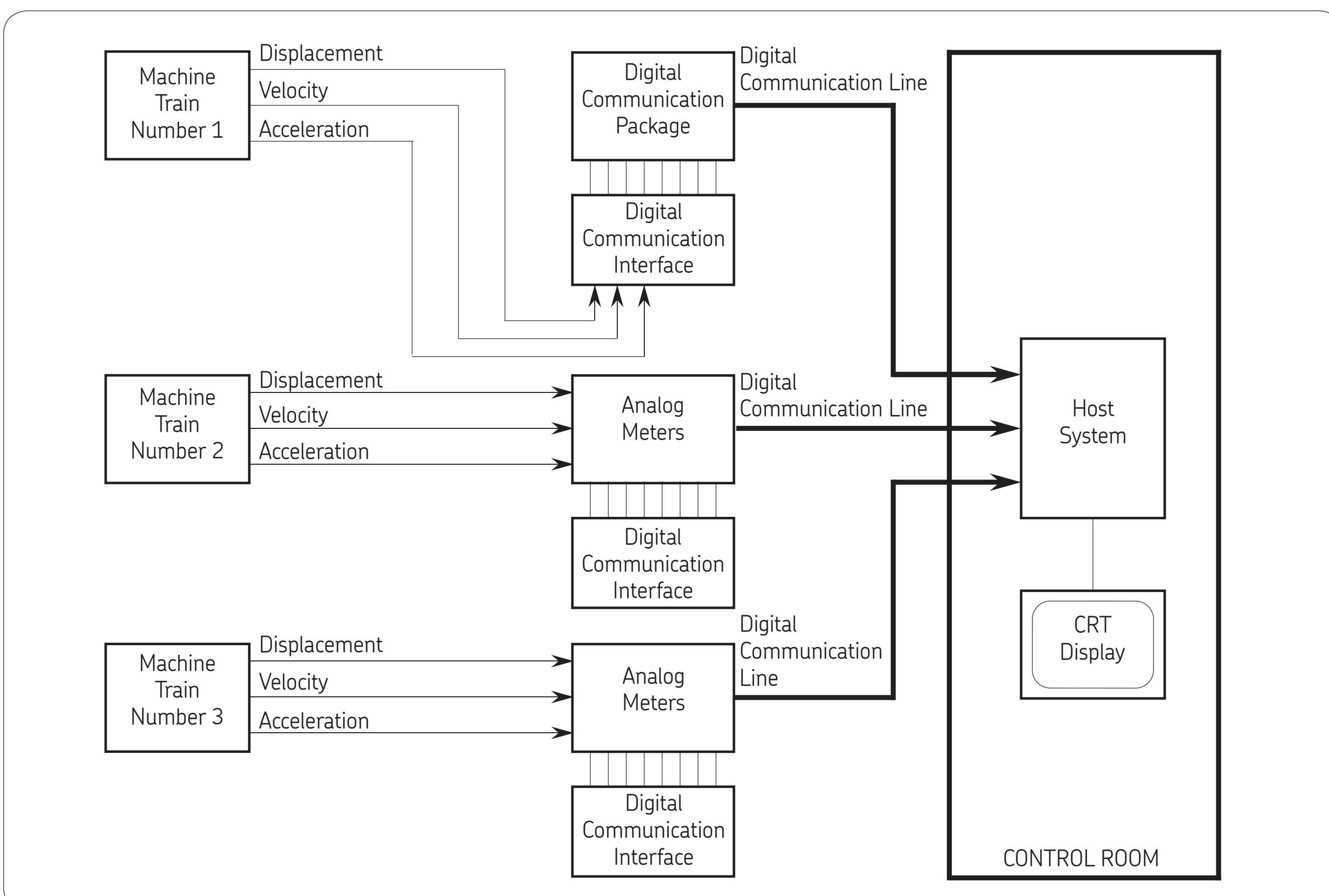


***Fig. 4. The serial communication adapter requires individual analog monitors for each transducer and provides a bridge between the analog and digital world.***

# Modern approach to protection and monitoring

The newest approach advances machinery monitoring while maintaining and, in many cases, exceeding the protection guidelines established by the API standards.

Through the use of highly reliable, industrial-proven microprocessors, this system incorporates the programmability and flexibility of digital technology at the front end.

Each two- or four-channel monitoring module is controlled by its own microprocessor, with separate, selectable analog detection circuits. This design allows the user the flexibility to program any channel to accept any acceleration, velocity or displacement transducer inputs with any sensitivity, select a RMS, 0-PK or PK-PK detector, or operate with any full scale range.

All of the alarm and relay functions are programmable and allow the user to program separate high and low alert and danger limits for each channel, individually program relay time delays and select either latching or non-latching relays. Certain specialized signal conditioning functions such as high pass, low pass or band pass filters and signal integration are also programmable.

This system introduces several new reliability features such as selective tripping within the system. Each monitor module is individually fused, isolating any shorts or monitoring system component failures at its source. Additionally, each transducer has its own separate power regulators ensuring that this type of failure does not leave a machine unprotected.

Another new concept introduced to the machinery monitoring world is alarm reflash. This function is designed to immediately inform the operator of any new or subsequent change in a machine's condition by using easily recognizable LED flash patterns. A unique on-board annunciator system reduces auxiliary costs for the monitoring system.

All system programming and communications are done via an internal digital interface bus, allowing easy expansion of the system while reducing the overall cost of system installation.

This system is designed as a distributed monitoring system since each monitoring module has its own microprocessor. Each of the monitoring modules store all of its parameters in non-volatile memory and is a stand-alone monitoring system. This design enhances the reliability of the monitoring system, since it does not rely on unreliable communications links for critical decisions, such as shutting down a machine. Individual processor or module failures affect only its associated channels, while the remainder of the monitoring system continue to protect the machine.

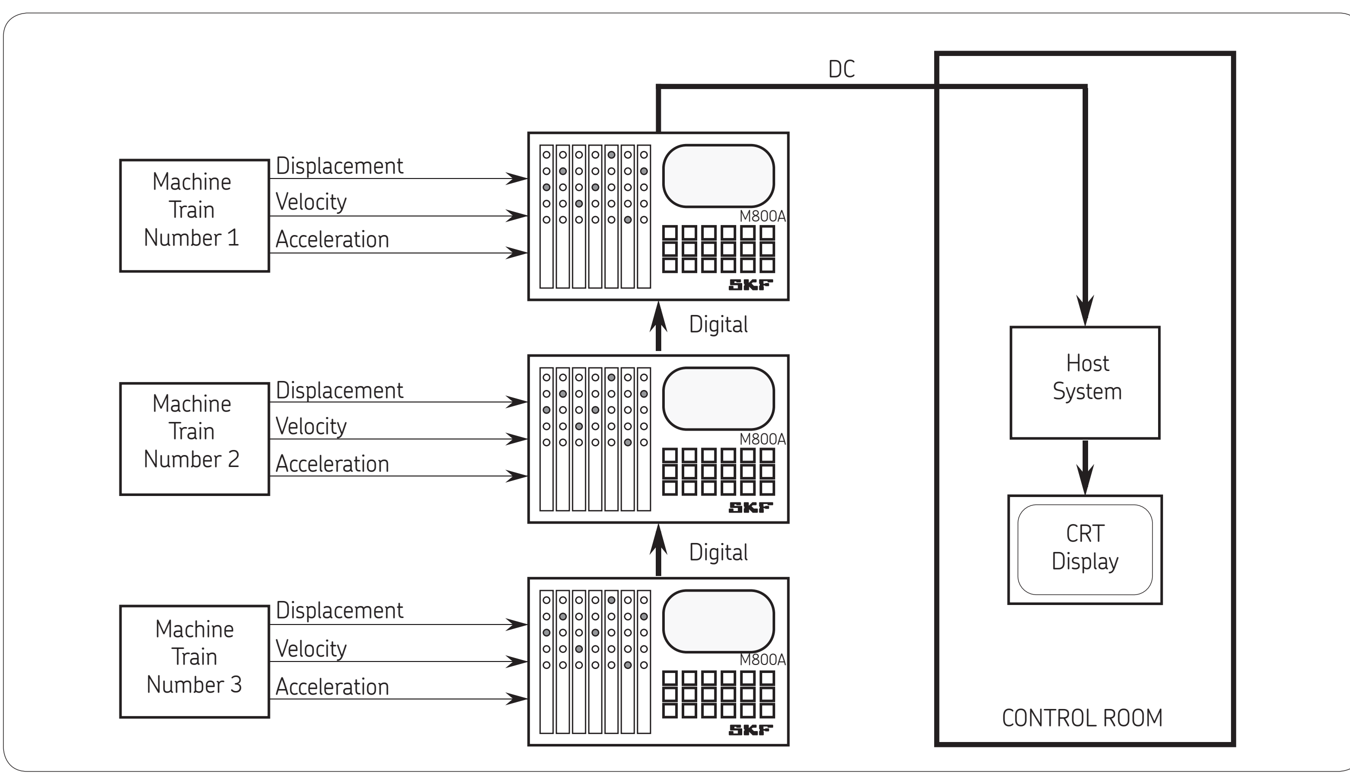


***Fig. 5. The modern system has microprocessor controlled conditioning cards that are designed to operate in today's digital environment.***

The programmability features of a monitoring system provides many advantages. Gains, delays, sensitivities, voting and other monitoring functions are programmable and can be stored in non-volatile memory at the plant site. The time required to design a system is reduced as well as reducing spares inventory requirements. When retrofitting the monitoring system, only those transducers that are worn out need to be replaced. Upgrading to newer and/or different type transducers can be accomplished by a simple program change when the installed transducers useful life is over.

Calibration, checkout and functional performance of the monitors are computer assisted, resulting in a faster and more thorough inspection and setup of the monitors. An optional serial communications port not only provides remote machinery condition information, but also allows the host system to become an interactive part of the machinery protection system.

Each monitoring module provides its own self-checks at the module level, on both the microprocessor and each individual transducer, to quickly confirm the proper operation of that module and I/O signals. The system controller provides an additional check of each module that greatly increases the reliability of the overall system.

This new monitoring system was designed as a family concept in which individual modules and systems are designed to operate in concert to each other, allowing for easy and economical expansion. The systems modularity allows the user to economically purchase that amount of protection the budget will tolerate and when the need arises, later upgrade the system into a full and complete plant-wide monitoring system. By combining digital design and distributed processing, the maintenance engineer is able to upgrade a plant's machinery condition monitoring to the same level of sophistication that is now monitoring and controlling the remainder of the plant systems.

Because of the new automated manufacturing techniques and commonality of components, this system provides API type monitoring at a cost per channel of between $500 and $600 for an average machine (13 channels per machine). The digital operation of this system eliminates the need for expensive modifications to interface with existing or new host computer or control systems, and provides the necessary information to evaluate the mechanical condition of your rotating equipment. Machinery designs and needs have transcended the period where transducers and analog meters provide the information and protection required to safely operate today's smaller yet increasingly more complex machinery.

This short review of the currently available "new concepts" in machinery monitoring and protection systems emphasizes the need for the machinery user and vendor – to take a hard look at their machinery condition monitoring and protection systems needs and requirements. Now more than ever, decisions should be based on more than the initial purchase price of a system. Consideration should be given to the system's functions. Is it adequate to simply monitor a machine or should it be protected? What is the overall cost to install and own the system? What are the mandatory spares requirements? Is it easily expandable? Does it use the latest design and easily replaceable components? How long can this design be economically supported? How can it be integrated into a new or existing control system?

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