Keeping an eye on the process

Understand key indicators, and control loop performance will increase

See related *predictive maintenance* story on page 80.

By Alireza Haji-Valizadeh

A predictive maintenance policy uses process diagnostics and performance analysis tools to focus maintenance resources mainly on problematic loops and components offering the greatest return on investment.

Surveys show there is considerable room for improvement in plant operations if the end user adopts an effective loop maintenance policy. This multi-industry loop audit survey reported only 32% of loops have acceptable or excellent performance. With that poor loop performance in mind, there are industries out there right now adopting a form of condition based maintenance (CBM) as a predictive maintenance policy.

The objective of predictive maintenance is twofold. The first goal is to address under-performing and problematic loops before they become a problem and where chances for unscheduled shutdowns are high. The second objective is to increase the cost effectiveness of the maintenance effort. This means you have to prioritize the maintenance of the various loops.

Two economically oriented methods help prioritize maintenance of loops on a plant-wide scale:

1. Prioritizing based on contribution to Unit Fluctuations Cost Model (UFCM).

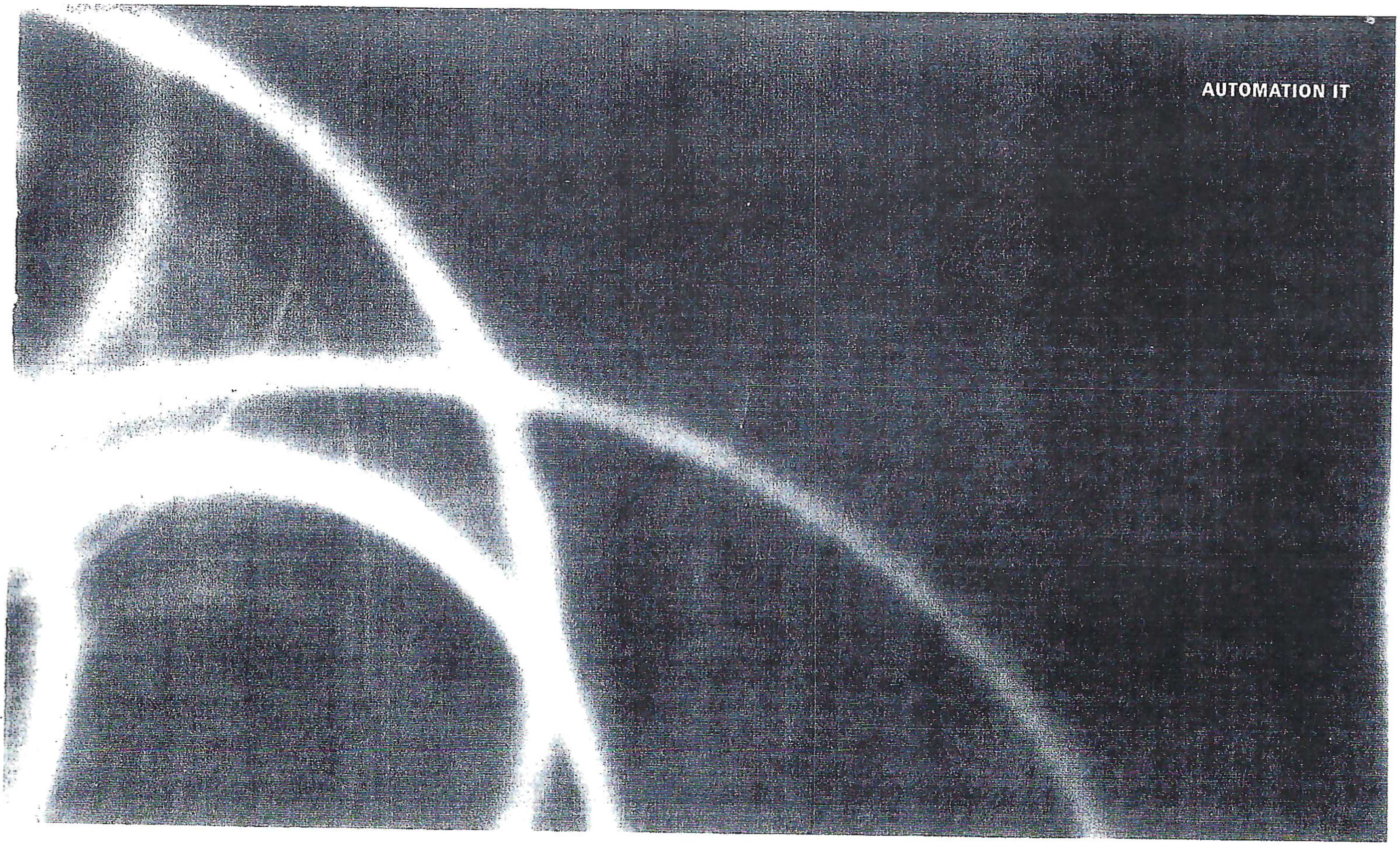
2. Prioritizing based on the contribution to Pseudo Fluctuations Cost Model (PFCM).

FAST FORWARD

- Industries are adopting a form of condition based maintenance as a predictive maintenance policy.
- In modern predictive maintenance, traditional key indicators should work in conjunction with newly defined methods and measures.
- An audit survey reports only 32% of loops have acceptable or excellent performance.
- Costs incurred because of fluctuations in the process variable or control output is the main factor for efficiency loss and a loop's poor performance.

Cost of unscheduled downtime

Having key indicators to measure the effectiveness of maintenance activities has long been a common practice. One commonly used indicator is the ratio of unscheduled process shutdowns to the sum of scheduled and unscheduled process shutdowns. An effective maintenance policy should drive this ratio to lower values over time. Other maintenance indictors may take into consideration the cost of maintenance in a budgetary period to eval-



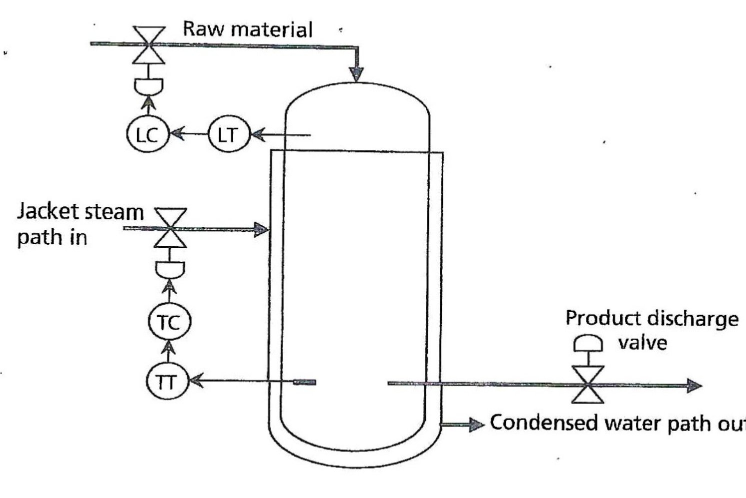
uate the efficiency of the maintenance in addition to its effectiveness. Maintenance indicators of this sort, which should provide information to managers, present few shortcomings when viewed in the framework of predictive maintenance.

For example, the indicator mentioned cannot determine if a specific controller of a process needs maintenance. It also cannot prioritize the maintenance effort. In modern predictive maintenance, the traditional key indictors should work in conjunction with newly defined methods and measures to render improved maintenance practices.

Incurred costs due to fluctuations in the process variable or control output are the main factors for efficiency loss and a loop's poor performance. Quality degradation of the product, loss of energy resources, waste of production, loss of production time, and shortened life time for process components are side effects of a fluctuating process.

Researchers and suppliers have suggested indicators for measuring process fluctuation. Examples are integral absolute error (IAE), standard deviation of error (StdDevE), and process variability (PVar), among others. Current practice in industry is to measure and calculate indices of this kind online, preferably by using moving time windowed analysis, then compare them against their historical optimum baseline values to determine if the corresponding loop needs maintenance. This practice improves when it incorporates the financial or monetary implications of the fluctuations in determining the need and the priority for maintaining a loop.

There are various ways to incorporate the economic implications of process fluctuations in predictive maintenance. A common theme in all methods relates process fluctuations to quality loss, resource waste, energy waste, and production loss and then quantifies the cost of these fluctuations. To this end, we could use



In a cooking vessel, the performance of the temperature controller directly affects the efficiency of the process.

material and energy balance laws that govern the underlying production, process dynamics, laws governing heat transfer and mass flow, properties of process materials, and the like in order to express the cost of fluctuations in the process variables and controllers' output (CO).

If you knew the financial model for the unit fluctuations, you could then calculate the percentile of contribution of each loop to the total cost of unit fluctuations in an online fashion. By ordering loops based on their contribution to the cost of fluctuations and setting up threshold levels for each loop's cost, you could determine the priority and the need for maintaining the loop.

Among the advantages are:

1. It is production-unit oriented.
2. It provides monetary measure for the underlying production unit's fluctuations.
3. It provides criteria for both determining the need as well as the priority of maintenance.
4. It incorporates different types of controllers (or loops) in the same maintenance scheme.

One serious disadvantage for this method, which could prohibit its practical application in a plant-wide scale, is the need for developing a monetary cost model for process fluctuation, which can be an expensive and cumbersome task requiring statistical analysis of process and financial data for the underlying unit. This requires time and extensive expertise and thus is a costly undertaking.

Batch process case history

Here is a simplified version of a real world batch process that consists of a cooking vessel.

First, raw material feeds into the vessel in liquid form. Then, the temperature of the material comes up to a desired level. After cooking the food at a certain temperature for a preset length of time, you discharge the food. A food-processing site has a number of these vessels working in cascade and parallel configurations to cook the foods for various recipes. A maintenance regimen for this site should determine when unit controllers need maintenance and how to prioritize maintenance among various loops.

The performance of the temperature controller directly affects the efficiency of the process. To increase the output of the process, raise the temperature to its set point as fast as possible and then maintain the temperature at its set point for a preset length of time. There are, however, two common fault modes for this process:

1. The controller behaves too slowly, which results in a loss of production time.
2. The controller behaves too aggressively, causing the temperature to overshoot its set point.

This second fault mode results in a buildup of a layer of burned food on the inside wall of the vessel. This heat insulating layer changes the dynamics of the heat-exchange process by increasing the time constant of heat-exchange process and consequently forcing the controller to saturate CO more easily and waste heating energy.

Despite CO saturation, the process temperature may take a long time to rise to its set point, which results in a loss of production time. Through this behavior, the process suffers from loss of energy and production time. Gradually, process operation degrades to an intolerable level until the user stops the operation. As a corrective action, flush the vessel with fresh water to remove the layer of burned food from the inside walls of the vessel. The flushing process results in further loss of production time and introduces extra cost for the operations. Although you can not avoid flushing completely, good maintenance of the process controller decreases the frequency of flushing.

One way to monitor the performance of the temperature controllers of the vessels is to measure the IAE of the corresponding controllers. When IAE exceeds a preset threshold level, the system releases a maintenance work. To prioritize maintenance activity, the precedence could go to maintaining the controller with the higher IAE. Two shortcomings are:

1. It does not suggest what should be the preset threshold level.
2. Among vessels that cook various recipes, which controller should be the first one maintained? A vessel cooking a highly priced product whose controller's IAE may not even trigger the issuance of a maintenance work order in the above scheme could be wasting more money than the maintenance-demanding vessels.

An improved maintenance method incorporates the cost associated with the fault modes in the decision-making process. To this end, we can model the cost of fluctuations as follows:

(1) Number of Flushes = f(IntegralPVPosDev)

(2) Production Time Loss Cost = Number Of Flushes × Cost Of Each Flush + g(IntegralPosErr)

Despite CO saturation, the process temperature may take a long time to rise to its set point, which results in a loss of production time.

(3) Energy Cost = h(IntegralNegErr)+ k(IntegralPosCO)

(4) Fluctuation Cost = Production Time Loss Cost + Energy Cost

In equations (1) through (4), relationships f(.), g(.), h(.), and k(.) are nonlinear. You might be able to approximate them by first-order linear functions by applying a least square curve fitting method to historical data.

In the above equations, IntegralPVPosDev is the integral of positive deviation of PV from a pre-known level at which the product starts to burn. As IntegralPVPosDev increases, the number of necessary flushes also increases. Buildup of temperature insulating layer inside the cooking vessel causes loss of the production time, captured in (2), through two mechanisms:

1. Increase of number of water flushes.
2. Increase of system time constant, which in turn results in higher values of g(IntegralPosErr), where Err=(SP-PV).

Energy is wasted in the system through two mechanisms:

1. Overheating the process that h(IntegralPosErr) captures.
2. Increasing the time constant and thus causing CO to push harder to achieve the same objective.

This second energy cost is in k(IntegralCOPos). You can now obtain the total cost of fluctuations as in equation (4).

Compared to the former method of prioritization, which depends on a single-loop assessment index IAE, this method depends on IntegralPVPosDev, IntegralNegErr, IntegralPosErr, and IntegralCOPos assessment indices. The advantage is this latter method provides a monetary maintenance KPI (i.e. fluctuation cost). Evidently this KPI makes it easier to establish a monetary threshold level for issuance of a maintenance work order for a controller. It is also easier to prioritize maintenance activity among a number of service-demanding controllers.

Lower cost model

As mentioned, obtaining a monetary cost model for the fluctuations of a unit in the UFCM method is, in general, an expensive undertaking. This may prove to be a prohibitive factor in applying this method on a plant-wide scale. However, an alternative method easily implemented on a large scale uses only three steps:

1. Developing a pseudo fluctuation cost model for the controllers.
2. Categorizing the loops based on their type.
3. Prioritizing the maintenance of controllers belonging to each type independently.

An appropriate pseudo fluctuation cost model is one that is: monetary; reflects roughly the cost associated with having poor performing controllers; and is easy to develop. Consider the following model that provides a pseudo fluctuation cost per one unit of time:

(5) Pseudo Fluctuation Cost = (IAE×Value of Processed Product) ÷ T

The principle used in defining the pseudo fluctuation cost in (5) is the cost associated with a poorly performing controller used in producing a valuable product is likely to be higher, and thus its maintenance should get precedence. In (5), T denotes the length of time during which IAE and the value of the processed product undergo evaluation. T for a batch process could be the batch time and for a continuous process could be the length of time it takes the process to reach its steady state (e.g. four times its dominant time constant). In (5), IAE captures the amount of fluctuations calculated using percent set point error; and the Value of Processed Product denotes the value of processed product in T. We could enhance the fluctuation cost function defined in (5) to include pseudo energy cost information. Equation (6) suggests one cost function in this realm.

Determining if a loop needs maintenance and prioritizing among service-demanding loops are basic steps of any predictive maintenance regimen.

(6) Pseudo Fluctuation Cost = (IAE × Value of Processed Product) ÷ T + (IntegralPosCO ÷ T) × Cost of Unit of Positive CO

For certain loop types, you could easily obtain energy cost. For temperature loops where the energy source is electricity or steam, the cost of energy (or power) is well known. For other loop types, the energy information may not be readily available, in which case, the cost model could exclude it.

Determining if a loop needs maintenance and prioritizing among service-demanding loops are basic steps of any predictive maintenance regimen. It is worth mentioning the two methods discussed are not mutually exclusive, and different methods could apply to different loops within the plant, but if used properly, these methods could help in a predictive maintenance program.

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