INSTRUMENT RELIABILITY - MAINTENANCE IN PROCESS PLANTS

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Abstract: Industrial processes continually require both operational performance and safety improvements, and these two requirements highlight the need for means of fault diagnosis. The development of condition-based maintenance techniques as opposed to planned maintenance or reactive (after failure) maintenance practices is a tendency that has shown impressive growth and promises to dominate the scenario in the near future. Instruments play an essential role in the achievement of the expected results, but the instruments themselves can be sources of unreliability and fault within industrial plants. An analysis of the main instrument maintenance challenges encountered in industrial process plants, and classification of the critical failure modes of the most important types of instrument employed are discussed. The various means to allow implementation of condition-based and life-time evaluation maintenance programmes for instruments are surveyed and an analysis of their applicability to help solve the listed problems is also developed.

Keywords: instrument reliability, process plant maintenance, fault diagnostics

1   INTRODUCTION

The traditional approaches to the problem of failure of industrial processes are threefold; (A) to provide a plan of maintenance which will replace worn parts before they malfunction or fail; (B) employ a scheme of monitoring which detects faults as they occur and compensate for the faults; (C) repair or replace parts after failure.

The adequate use of one of these methods or combinations of them can lead to satisfactory levels of reliability. Approach (A) demands the use of some kind of lifetime prediction methodology. For option (B) a mathematical model is usually required; some simple applications can be performed with the use of plain Boolean logic, but in most of the cases a rather sophisticated modelling must be employed. Approach (C) is the simplest one and its application asks only for the ability to detect which component is responsible for a faulty operational condition after its occurrence. The decision on which solution to adopt depends on the nature and hazard of the process, the costs involved and the degree of risk one is prepared to allowed to run.

When one talks about process control and automation, there is a broad range of applications. For example, consumer goods manufacturing, chemical and petrochemical processes, mining, sophisticated metals and steel production processes, conventional and nuclear power generation plants, automation and control systems for aerospace vehicles. Each application sector must deal with faults in appropriate ways.

Procedures to determine the force of mortality (FOM) of parts or the rate of occurrence of failures (ROCOF) for systems are well established. When sufficient statistical data are available, a plot of the FOM against the part age, or the ROCOF against the cumulative operating time of the system can be drawn, and it generally takes the form of the curve in Figure 1, the >bathtub= curve.

There are three distinct regions of the curve, relating to three different failure processes. Region á corresponds to the early failure or >infant mortality= phase, when those items that are in some way weak or defective will yield before their expected life. After all the defective items have failed the system reaches region â and assumes a constant or slight crescent ROCOF. This is the so-called useful life phase and failures within this region occur unpredictably by chance. The last region ã is reached when the components of the system are approaching the end of their designed life and the ROCOF increases pronouncedly with time; this is the wear-out period.

In industrial applications, efforts are often made to ensure that an item is only operated in its useful life phase. The avoidance of problems in region á is quite simple to be achieved with electronic parts submitting them to burn-in processes before delivery for use, but it is not so straightforward for mechanical components. On the other hand concerning region ã , mechanical parts are more likely to have trustable previsions of wear-out than the electronic ones. The kind of instruments we are interested in are in general

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a mixture of mechanical and electronic parts, so that there is always some risk in the assumption of a constant ROCOF.
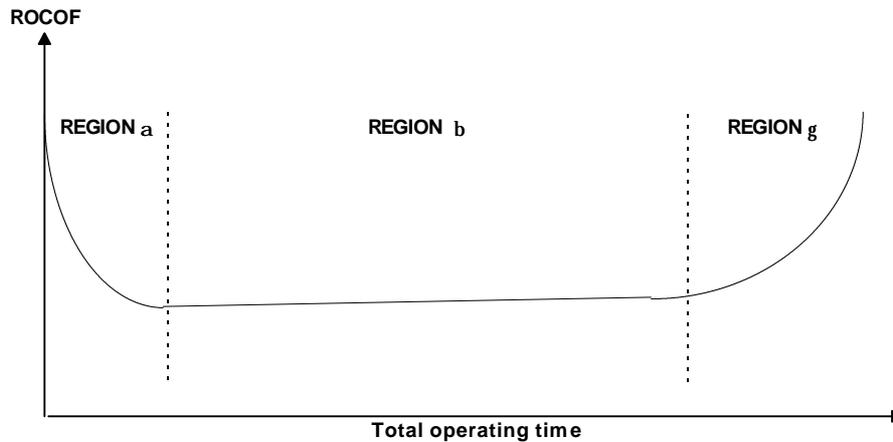

Figure 1. The bathtub curve.

2 INSTRUMENT SYSTEMS

Reliability models can be applied to any science or engineering branch. Monitoring and automation instruments are not necessarily involved [1]. Instruments do play an essential role in the use of automation systems in general and of fault tolerant systems in particular, since they are the link between the process and the mathematical models employed. The more complex or sophisticated the system the larger will be the number of instruments demanded and the greater their importance to the well working of the whole scheme. But instruments themselves are subject to failures, and this converts them from being solutions to becoming part of the problems.

To work properly, the control algorithms and reliability models depend fundamentally on the information the instruments supply, or more precisely, on the bi-directional interface instruments play between them and the process. While in some reliability applications it is sufficient to distinguish between two exclusive states, working and faulty, in the case of instruments the problem can be a lot more complex. Apart from total failure it is necessary to decide whether or not the instrument is working within its defined limits. An instrument system which appears to be working correctly, but is making inaccurate measurements of manipulating a process variable in disagreement with the signal received can lead to more serious consequences than one which has obviously failed. Recognition of revealed failures that annihilate one or more functions of the instrument system are not a problem. To deal with the unrevealed failures which allow the operation of the system, but with unacceptable performance is, however, quite a complex task [2]. When a system involves feedback control there is a greater complexity of fault detection as it is difficult to distinguish between sensor, actuator and process malfunctions [3].

There is a growing recognition of the key importance of reducing process plant maintenance costs through improved reliability and self-checking features of measurement instrumentation. Unnecessary disassemble of the instrument systems or unexpected shutdowns due to unpredicted malfunctions might be avoided by use of a condition-based evaluation methodology allowing prediction of the lifetime of instruments.

3 INSTRUMENT RELIABILITY DATA

A general work about field instruments operating in process industries found was published in 1971 [4]. It provided a set of standardized man-hour ratings for instrument maintenance. During the 1960s reports on studies relating to failure rates of instruments, mainly in nuclear power plants, were published [5][6][7]. The 1970s saw publications regarding failure rates of instruments in chemical plants [8][9][10][11]. One survey involved 8000 instruments in a heavy organic chemicals plant, 950 instruments in a heavy inorganic chemicals plant, and 440 instruments in a glass works. Various other papers provided reliability data mainly for electronic components [2][12].

Fault detection and isolation (FDI) schemes exist [13]. For example hardware redundancy is employed in aerospace and safety-critical process plants [11]. There are three main methods of FDI: (I) analytical redundancy (AR) methods, (II) knowledge-based methods (KBM) and (III) measurement aberration detection (MAD). All methods require fairly complex mathematical models [13][14][15].

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The MAD method involves an examination of the outputs of sensors for indication of faults [16]. Characteristics of the measurement signal in the time and/or frequency domain are acquired to compose a >baseline= model of the >healthy= system. The output of the sensor is decomposed into two components: a low frequency one related predominantly with the measurement signal and a high frequency one related with measurement noise. Analysis of the output signal using a suitable mathematical model can detect deviations from the >healthy= condition. A decentralized and hierarchical fault detection structure is used. The self-validating instrument (SEVA) approach [3] makes use of >smart= sensors and actuators and digital communication procedures; the field instruments generate codes to represent the status of their >health= and the corresponding uncertainty associated with their operation [17].

Failure rates of the most commonly employed instruments are shown in Table 1 [8].

Table 1. Instrument failure rates.

instrument class	average failure rate (faults/year)
Thermoelements and thermometers	0.35
Control valves and accessories	0.52
Differential pressure (D/P) transmitters	1.72
Flow measurement devices/transmitters	0.82
Process switches (level, temp., press., flow)	0.35
Level measurement devices/transmitters	1.69
Pressure transducers	1.41
Analysers	8.49

Analyser faults are usually related to sample systems and associated hardware [18]. Life-time evaluation can be used, for example by monitoring for sample line obstructions. Failure faults can be abrupt (sudden) or incipient (slowly developing) [13]. The authors have established the main failure modes of sensors and control valves and their implications. To limit some of these failure modes, lifetime evaluation schemes can be implemented.

4   CONDITION-BASED MAINTENANCE

There are two major failure modes: gradual degradation in instrument performance because of the process, and instrument wear-out. In both cases failures are situated in the ã region of the bathtub curve (Figure 1), since most failures are incipient.

Condition-based maintenance is of growing importance [19][20][21]. A common limitation is the need to avoid generation of false alarms. AR methods allow early detection of failure, but to implement requires an accurate mathematical model of the system and abrupt changes cannot be predicted. KBM methods do not require a mathematical model, and they can be designed so that failure diagnosis, symptom interpretation and maintenance scheduling are built-in tools of the shell package, provided a suitable supporting knowledge-base is available.

MAD methods require only mathematical models of each instrument, and knowledge is transferred to the instrument such that a >signature= for it and its surroundings is obtained. This allows the monitoring of evolving changes to the signature for condition-monitoring purposes. The nature of the problem is not determined, but complementary techniques can be used for this purpose.

The SEVA approach is promising. Here the aim is to look for symptoms, not monitoring inconsistencies and local validation. Features held in the instrument such as signal checking, uncertainty and status inform continuously the health conditions of the instrument. Diagnostics are performed at a higher level of operation.

Statistical distributions are widely used in the reliability field [2], and might be applied with benefit to the industrial instrumentation field. Hazard curves based on ROCOF for instruments would be employed with statistical models.

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