CHAPTER 2

SYSTEM DESCRIPTION

2.1 INTRODUCTION

Pneumatic valve is commonly used in modern process plants to control the flow of a fluid, gas or slurry. The main function of this pneumatic valve is to regulate the flow rate in a pipe line. There are several problems and faults occur in pneumatic valve, when it works continuously. A fault in pneumatic valve may lead to a halt in production for long periods of time. Apart from these economic considerations fault in pneumatic valve may also have security implications. A fault in pneumatic valve may be danger to human lives, as in the case of a fault in the stem position control system of a cement industry. The occurrence of faults in pneumatic valve can be reduced through preventive maintenance; however, they cannot be fully eliminated. Therefore, there is a need for fault diagnosis systems that detect and diagnose a fault as soon as it occurs.

2.2 DESCRIPTION OF PNEUMATIC VALVE

The pneumatic valve is widely used to control the distribution of water with the help of stem position. Faults in pneumatic valve are usually the main cause of loss of productivity in the cement industry. This valve is subject, relatively often, to faults and malfunctions due to harsh environment conditions, which cause a decrease in production or even an installation shutdown. The design and performance testing of fault diagnosis systems in
pneumatic valve often requires a simulation model since the actual system is not available to generate normal and faulty operational data needed for design and testing, due to the economic and security reasons that they would imply. The next section describes the physical structure of pneumatic valve.

2.2.1 Physical Structure of pneumatic Valve

The flow control valve is a final control device that acts on the controlled process. Most of these valves are pneumatically actuated, consisting of three main parts: body of the valve, pneumatic servomotor and positioner controller. The internal structure of the pneumatic valve is shown in Figure 2.1. The valve body is the component that determines the flow through the valve.

The positioner is the control element that performs the position control of the stem. It receives a control reference signal (setpoint) from a computer controlling the process, then the changes in the reference signal is given to the Proportional Integral Derivative (PID) control to take necessary action. The positioner comprises of a position sensor and an electro-pneumatic (E/P) converter. It determines the actual position of the stem so that the error between the actual and desired position (reference signal) can be obtained.

The E/P converter receives a signal from the PID controller transforming it into a pneumatic valve opening signal that adds or removes air from the PS chamber. This converter is also connected to a pneumatic circuit and to the atmosphere. If the controller indicates that the stem should be lowered, the chamber is connected to the pneumatic circuit. If on the other hand, the stem should be raised, the connection is established with the atmosphere, thus allowing the chamber to be emptied.
From the water reservoir to flow nozzle for water spray in the hot gas duct.

- **PSP**: Positioner of supply air pressure
- **PT**: Air pressure transmitter
- **FT**: Volume flow rate transmitter
- **TT**: Temperature transmitter
- **ZT**: Rod position transmitter
- **E/P**: Electro-pneumatic converter
- **V₁, V₂**: Cut-off valves
- **V₃**: Bypass valve
- **PS**: Pneumatic servomotor chamber
- **CVI**: Controller output
- **CV**: Control reference value
- **F**: Volumetric flow
- **X**: Servomotor rod displacement

**Figure 2.1 Internal Structure of the Pneumatic valve**
The flow through the valve is given by

\[ F = 100k_v f(x) \sqrt{\frac{\Delta P}{\rho}} \]  

(2.1)

where \( k_v \) is the flow coefficient (m\(^3\)/h) (given by the manufacturer), \( f(x) \) is the valve opening function, \( \Delta P \) is the pressure difference across the valve (MPa), \( \rho \) is the fluid density (kg/m\(^3\)), \( F \) is the volumetric flow through the valve (m\(^3\)/h), and \( x \) is the position of the rod (m), which is the same as that of the plug. The valve opening function \( f(x) \) indicates the normalized valve opening area. It varies in the interval \([0, 1]\), where the value 0 indicates that the valve is fully closed and the value 1 indicates that it is fully open. The value of \( x \) is defined as the percentage of valve opening.

### 2.3 FAULTS IN PNEUMATIC VALVE

In process industry the maintenance strategy could be predicted to monitor the condition of control valves and their associated accessories such as actuators and positioners. Consequently, the plant accessibility will improve and the loss of production due to the unpredictable faults will be considerably reduced. There are several common symptoms and faults that indicate abnormal conditions of pneumatic valve in operation. The major categories of faults in the pneumatic valve include control valve faults, pneumatic servo-motor faults, positioner faults, general faults/external faults. The individual faults in each category along with their symbols are listed in Table 2.1. The control valve may be affected by a number of faults (Koj, 1998). Control valve faults are faults that affect the valve body. There are six different faults for this type: valve clogging (fault F1), valve seat erosion (fault F2), valve seat sedimentation (fault F3), increased bushing friction (fault F4), external leakage (fault F5), internal leakage or fault in valve tightness (fault F6) and critical flow (fault F7).
Fault F1, valve clogging, occurs when the servomotor stem is blocked by an external event of a mechanical nature. This fault does not permit the stem to go above a certain position and therefore the flow cannot drop below a certain value. Restricting the stem motion to a smaller range simulates this fault. Fault F2, valve plug or valve seat erosion, occurs when the continuing flow starts to remove material from the valve plug or the valve seat, which alters their dimensions. The altering of the dimensions causes the flow coefficient $k_v$ to increase, the stem position is to higher and there is a change in the position of the stem because the force exerted by the fluid higher. A simultaneous increase of $k_v$, an alteration of the stem motion, and an increase in its range simulate the fault.

Fault F3, valve plug or valve seat sedimentation, occurs when solid particles are mixed with the liquid. These solid particles starts to sediment in the valve plug or in the valve seat reducing the orifice dimensions. The altering of the dimensions causes the $k_v$ to decrease, the stem position is to smaller and there is a change in the position of the stem because the force exerted by the fluid is smaller. A simultaneous decrease of the flow coefficient $k_v$, an alteration of the stem motion, and a decrease in its range simulate the fault.

Fault F4, increased bushing friction, occurs when the normal force and static friction coefficient on the valve stem packing box increases due to corrosion, sedimentation and pollution. This causes the hysteresis that already occurs in the stem to be increased. This fault is simulated by an increase in the hysteresis of the stem motion.

Fault F5, external leakage, occurs when the valve has a leakage, caused by corrosion, mechanical wear or poor assembly. This fault entails a loss of flow to the environment. This fault is simulated by a reduction in the flow at the output of the valve.
<table>
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<th>Types of fault</th>
<th>Name of the fault</th>
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<td></td>
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<td>F17</td>
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Fault F6, internal leakage, occurs when there is a loss of valve plug–valve seat tightness due to erosion, corrosion or mechanical wear. This fault is simulated by an increase of the flow coefficient $k_v$. 
Fault F7, critical flow, occurs when there is a failure in the internal component of the valve. There are four faults that fall into this category: twisted servomotor stem (fault F8), servomotor housing tightness (fault F9), diaphragm perforation (fault F10), and spring fault (fault F11).

Fault F8, twisted servomotor stem, may occur when the stem is bent due to external or internal forces parallel to the stem’s axis. This will cause the normal force on the valve stem-packing box to increase and therefore cause an increase in hysteresis. This fault is simulated by an increase in the hysteresis that affects the stem motion.

Fault F9, servomotor housing tightness, occurs when there are air losses due to the lack of tightness of the pneumatic chamber. These air losses have an influence on the chamber pressure. This fault is simulated by a reduction in the airflow into or from the pneumatic chamber.

Fault F10, diaphragm perforation, occurs when the flexible diaphragm is punctured due to fatigue of the material. This causes a loss of air from the pneumatic chamber to the atmosphere, which alters the chamber pressure. This fault is simulated by a reduction in the airflow into or from the pneumatic chamber and in the area of the flexible diaphragm. Fault F11, spring fault, occurs when the spring, which supports the stem, has a fault due to corrosion and/or fatigue of the spring’s material. There are three main faults that affect the positioner: E/P converter fault (fault F12), stem displacement sensor fault (fault F13) and positioner feedback fault (fault F14).

Fault F12, E/P converter fault, occurs when the characteristics of the converter are changed due to coil damage or mechanical fault. This fault is simulated by changing the output of the E/P converter, which will affect the airflow into or from the chamber.
Fault F13, stem displacement sensor fault, occurs when the potentiometric sensor responsible for supplying the measurements of the stem’s position is faulty, due to wear of the materials or wire breaks due to fatigue. This fault is simulated by an increase, or decrease, in the readings of the position sensor.

Fault F14, positioner feedback fault, is caused by fault of a spring cancelling the clearance in the positioner mechanical lever feedback system. This fault is simulated introducing hysteresis in the feedback portion of the control loop, not affecting the sensor reading. General/external faults are faults whose origin is not in the flow control valve system but rather in the plant installation, but may affect the valve’s performance. There are four main faults that fall into this category: positioner supply pressure drop (fault F15), unexpected pressure change across the valve (fault F16), increase of pressure on the valve output (fault F17) opened bypass valve (fault F18) and flow sensor fault (fault F19).

Fault F15, positioner supply pressure drop, occurs when the pressure of the pneumatic circuit that connects with the positioner drops. This causes the airflow into the chamber to be altered. This fault is simulated by a reduction of the pressure of the pneumatic circuit.

Fault F16, increase of pressure on valve inlet, occurs when, for some reason related to the system where the valve is placed, the pressure difference across the valve is altered. It causes changes in the flow and in the stem position. This fault is simulated by a change in the values of the upstream pressure or the values of the downstream pressure.

Fault F17, increase of pressure on valve output, occurs when, changes in the value of upstream or the values of downstream pressure. Fault F18, opened bypass valve, occurs when the valve of a bypass circuit, used to
allow the control valve to be changed without stopping the flow, is opened, either due to employee mishandling or to a fault in this valve. This fault will lead to a greater flow at the exit of the circuit than what would be expected. The fault is simulated by an increase in the flow through the valve.

Fault F19, flow sensor fault, occurs when the sensor responsible for measuring the flow is faulty due to electronics or wiring failure. This causes the flow measurements to be biased. This fault is simulated by an increase, or decrease, in the flow readings. A complete description of the faults and the way they affect the valve are given in (Louro 2003).

2.4 DEVELOPMENT OF FAULT DIAGNOSIS SYSTEM

To develop the fault detection and diagnosis model the following intelligent computing techniques are proposed.

a) Fuzzy rule based system and

b) Artificial Neural Network (Backpropagation Neural Network, Radial basis function network, Auto-associative neural network)

c) Adaptive Neuro-Fuzzy Inference system

Fault detection and diagnosis is a classical area for FL applications. The advantage of FL based approach is that it gives possibilities to follow human way of fault diagnosing and to handle different information and knowledge in a more efficient way. The information required for the development of the fuzzy system was collected from the experts in cement industry. The industry selected for the research work is The India Cements Limited, Tirunelveli, located in southern part of Tamilnadu. The certificate obtained from the cement industry for the implementation of this research work is attached at the Appendix 1 of this thesis work. The collected
information includes the fault-symptom relationship and the ranges of the variables. The objective here is to capture the implicit knowledge behind the diagnosis process, which is embedded in the information collected from the experts through the developed model so that it can be applied for the diagnostic process when the process industries in operation.

The neural networks are able to handle continuous input data, and the learning must be supervised in order to solve the fault detection and diagnosis problem. Due to their powerful nonlinear function approximation and adaptive learning capabilities, neural networks have drawn great attention in the field of fault diagnosis. The proposed methodologies for fault detection in the system considered are based on Multilayer Feedforward Neural Network (MLFFNN), Radial Basis Function (RBF) network and AutoAssociative Neural Network (AANN). The information required for the development of the neural network and principal component analysis models for fault detection were collected from the field experts, the operational log book, operating manual and maintenance records which are maintained by the operators in cement industry.

2.5 SUMMARY

In this chapter, the details about description of pneumatic valve used in cooler water spray system selected for this research work from cement industry is given. The detailed descriptions of the various faults in the pneumatic valve which are considered for the study are presented. Further the development of fault diagnosis system using intelligent computing techniques are also presented.