Fault Detection and Diagnosis Using Rule-Based Support System on Fatty Acid Fractionation Column

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Abstract

This paper presents a unified approach to process fault detection and diagnosis (FDD) intelligent program for pre-cut fatty acid fractionation column. Process history based methods (rule-based feature extraction) is used to implement the FDD rule-based support system. Plant model was simulated by using an existing commercial process simulator – HYSYS.Plant™ software in order to compute the confidence region. Warning limits for process parameters (temperature, flow rate and pressure) are computed by using statistical techniques. The uncertain information represented on three discrete states 'high, normal and low' in production rules form. Process variables are defined as fault if they are deviated outside this region. Identification of causes, consequences and suggested actions for each deviation assisted by Hazard and Operability Study (HAZOP) analysis are generated into rule-base algorithm. Forward chaining strategy is used to interpret the rule-based system. The whole system has been developed using Microsoft Visual C++ programming language. The system was founded to able to detect faults and promptly diagnose them.

Keywords:

Fault detection and diagnosis, Rule-based Support System, Process history based, HAZOP, Statistical technique

Introduction

In recent years there has been an increased emphasis on process safety as a result of a number of serious accidents. This is due to the worldwide attention to issues in the chemical industry brought on by several dramatic accidents involving gas release, major explosions and environmental incidents. Public awareness of these and other accidents have provided a driving force for industry to improve its safety record.

A number of major accidents in developed countries since 1984, such as the Piper Alpha oil platform fire (1988, 167 killed), the Zeebrugge ferry disaster (1987, 167 killed), Phillips petroleum fire and explosion (1989, 23 killed), the Challenger disaster (1986, 7 killed), Esso Australia Longford explosion (1998, 2 killed) have taken place [1].

The fault diagnostics of very complex systems has gained extreme importance due to unsatisfactory control or missed diagnoses of failures. The chemical process industries constitute one of the safest manufacturing sectors, but a single major accident or disaster can do irreparable damage to a company's reputation and possibly affect the entire industry. One main reason the chemical industry gets bad press is that its activities are very noticeable.

The success of industrial plants depends on their correct and safe operation. Due to the increasing complexity and necessity for this safety, efficient monitoring and supervision systems are becoming more and more important. This required not only an effective control, but also a fault diagnosis system for the chemical process. There is a pressing need for a computer-based solution or a knowledge-based system for automated supervision because of the difficulty to control by ordinary field operators.

This paper aims to formulate fault detection and diagnosis algorithm based on an expert system approach, where is one of an artificial intelligent tools. The functions of this algorithm are to ensure safe operation and provide information for plant operator, such as causes, consequences and actions. This research hopes to improve safety, productivity and quality during operation. It can be used as a tool to the operator in the case of process malfunctions, to improve security, reduce the number of shutdowns and downtime and thereby increase production. A fatty acid fractionation column has been chosen as the case study.

Problem Background

Due to the complexity and necessity of safety in industrial processes, efficient diagnosis system is becoming much more important. In order to operate successful plant, continuous improvement must be made in the areas of safety, quality and reliability. Although some fault detection and diagnosis (FDD) system have been invented for many industrial continuous production lines, but there is still no specific FDD system for olechemical plant – fractionation

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column. So, it is important to find out the effective and adaptable method due to the different kind of process operation in fractionation column. Knowledge engineering and advanced software tools such as expert systems have opened a new approach for the design of online process supervision. The main purpose of this research is to determine the appropriate method in building a worthy FDD support system based on expert systems approach.

Approach and Methods

The fault detection and diagnosis (FDD) support system created was based on process history, one of the common fault diagnosis methods [2]. Process history based methods need a large available historical process data. It was contrasted to the model-based approaches where a priori knowledge about the process is needed. Rule-based expert system approach and statistical feature are used to build the whole algorithm aided by statistical techniques and HAZOP methods. This case study used the combination of the two methods (expert system and statistical techniques) to overcome the limitations of the individual solution strategies. The first sub title section describes the procedure to design fault detection algorithm where consist the step of designing plant model and the control limits. The following sub title section describes the fault diagnosis algorithm. Hazard identification technique, HAZOP is used to define the potential hazard (cause) of the plant. Meanwhile the last section describes the development of support system and the strategy to interpret the expected results.

Fractionation column (production facilities), one of the dynamic engineering system, can be characterized by continuous-time operation. The existing commercial process simulator – HYSYS Plant™ software is used to model the process of fractionation column. Values for each different parameter from the plant model corresponding to the normal mode are used to generate the control limit as threshold for fault detection part. Warning limits, which are essentially the probability limits are set at 0.025; ±2 standard deviation is chosen. Fault is detected by comparing the measured with the threshold range. Fault diagnosis part is based on hazard identification technique, HAZOP. Figure 1 shows the Fault detection and diagnosis module.

Development of Fault Detection Algorithm

The development of fault detection algorithm is referred to the dynamic simulation developed by Wong [3] and presented in rule-based form, If - Then. Process parameters such as temperature, pressure and flowrate based on sensor outputs in the real plant are used to estimate acceptable range of operation parameter, warning limits (threshold). The values of warning limits are presented in the rule-based form. Fault is detected if process parameter from the operating plant is out-of the warning limits.

Process Modeling and Flowsheeting

The distillation process identified by using a rigorous dynamic model and simulated using industrial dynamic flowsheeting software, HYSYS Plant™. Mathematical modeling approach is no longer used to model the process, since the process is considered as a complicated chemical process. HYSYS simulator consist all the functions and can be modified in accordance to any changes of the process. The process operates in normal and also in the fault free conditions. Figure 2 shows the column environment of pre-cut column.

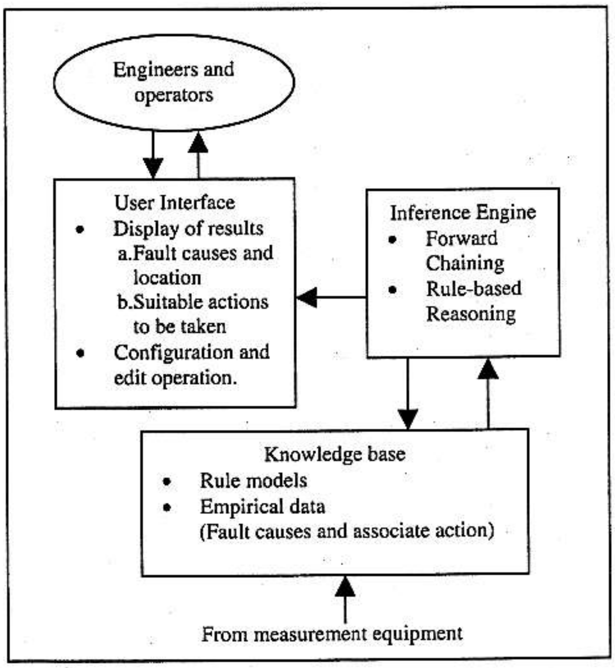

Figure 1 - Fault detection and diagnosis module

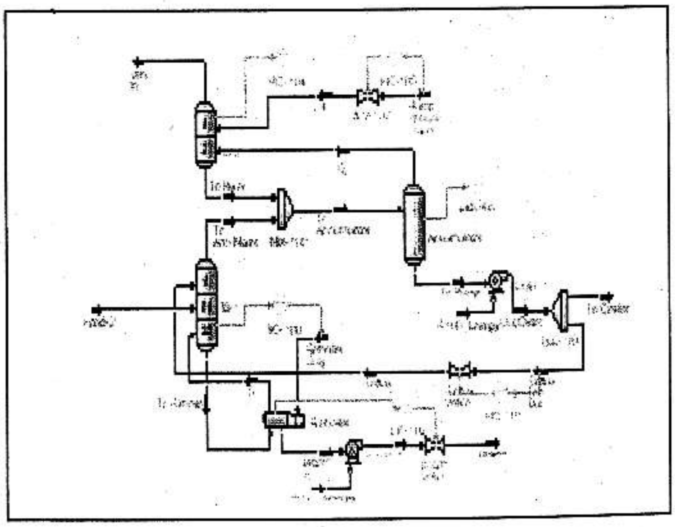

Figure 2 - Column environment for Pre-Cut Column

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Computing the Warning Limits

The approach of statistical process control (SPC) is used to compute the region of warning limits. SPC, used for charting the process and determine either a process is out of control. The control chart detects assignable causes where special causes variation is present when something unusual is occurring in the process. Management operator and engineering action will be eliminating due the assignable causes. Most processes do not operate in a state of statistical control. If these causes can be eliminated from the process, variability will be reduced and the process will be improved. The main purpose of using SPC is the statistical technique i.e. any deviation of the process operation parameters depend on the Probability distribution - mean and standard deviation (SD) that have been determined [4].

A typical control chart has control limits set at values in which if the process is in control, nearly all points will lie between the upper control limit (UCL) and the lower control limit (LCL). The upper and lower limits are constructed using the average or mean value and the standard solution deviation from a group, which about 60 samples of a standard solution measurements. ± 2SDs are used to establish the upper and lower warning limits and ± 3SDs are used to determine the upper and lower control limits. A mean chart can be constructed from the calculated mean and SD. The process is out of control where at least one point plots beyond the control limits. If the points behave in a systematic or nonrandom manner, then the process could be out of control.

The following show the formula that has been used to define the lower (LWL) and upper warning limits (UWL):

$$LWL = X + 2\sigma \quad (1)$$
$$UWL = X - 2\sigma \quad (2)$$

where X, mean of the sample.
σ, standard deviation.

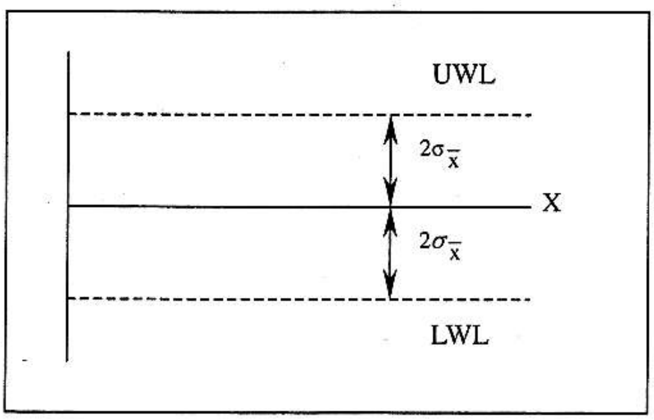

Figure 3 - The Interval Statistical (UWL and LWL)

Development of Fault Diagnosis Algorithm

HAZOP study results are used in developing the rule-based for fault diagnosis section. It is the important role in this FDD support system. The HAZOP technique applies the combination of "Property Words" and "Guide Words" to generate deviation from the design intent. This is systematically applied to all parts of the system such that hazard and the operability problems are eventually identified. Table 1 shows the HAZOP study results on Pre-cut Column of Sensor TI4024 with temperature parameter. The outline below shows the steps used in the HAZOP procedures:

i. A unit is selected from the process.
ii. The Property Words (parameters) is applied.
iii. The Guide Words due to the parameters above applied to give the deviation.
iv. Causes, consequences and the existing "Safeguard" are then identified.
v. The appropriate actions are decided to eliminate or mitigate the identified problems.
vi. Other relevant Property Words and Guide Words are repeated to the unit.

Table 1 - HAZOP studies on Pre cut Column – Sensor TI4024 Parameter: Temperature

Guide Word	Deviation	Possible Cause	Consequences	Action Required
High	High Temperature	Temperature Indicator TI 4002 fails		Check for indicator TI4002.
		Heating Medium (TT4402) overheated.	Thermal expansion of pipings.	Check TT4002 is equipped expansion bellow for thermal expansion
		Process upset	Precut column will overheated	Check TT 4402 design temperature if it can handle the heating medium overheated.

Architecture of the FDD Support System

The proposed FDD support system consists of three structure components: warning limits and HAZOP knowledge base, inference engine and user interface. Warning limits and HAZOP knowledge base were constructed during the development stage of the expert system. Users cannot modify it. This system was developed on windows operating environment. Microsoft Visual C++ language was employed in the development of FDD support system.

Implementing Knowledge Base and Inference Engine

The warning limits are stated by using switch case statement. The process will carry on associated with the choices that have chose by user, and then others will be ignored. Meanwhile, HAZOP knowledge base is stated in *if-else*

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statements; Yes is for the *if* part; No is for the *else* part. If the condition is true, the statements within the first set of braces are executed; the *else* part is ignored. If the condition is false, the statements in the braces following *else* are executed and the first set of statements ignored. Both of the statements operates just the way as forward chaining, where one of the form of inference mechanism formally using in the expert system. An example of *if-else* statements shows in the results section.

Creating User Interface

The user interface deals with the communication between the user and the FDD support system. All the results will presented to the user via the interface. The user interface was created using the Microsoft Foundation Classes (MFC) and Visual C++. Figure 4 shows the developed window environment in implementing support system using Microsoft Visual C++ version 6.0.

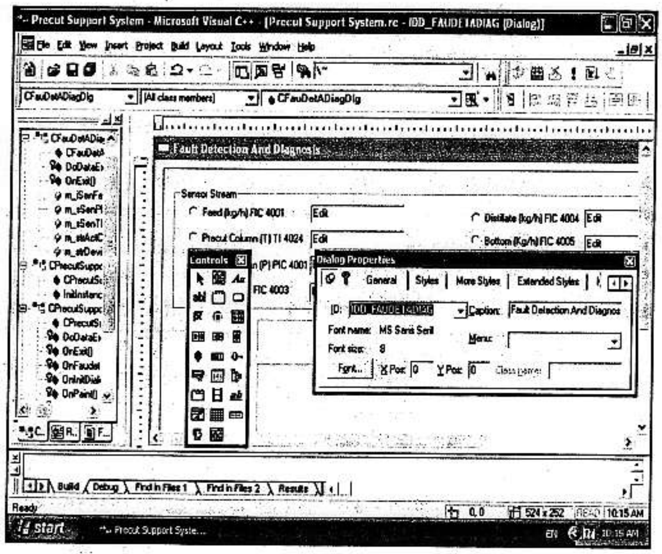

Figure 4 - Development Studio Environment Visual C++

Results

Warning limits for each sensor that calculated by the aid of Microsoft Excel using 60 values collected from the Pre cut simulation. The samples of calculations are show in Figure 5. Table 2 shows the results of upper and lower warning limits that had been calculated.

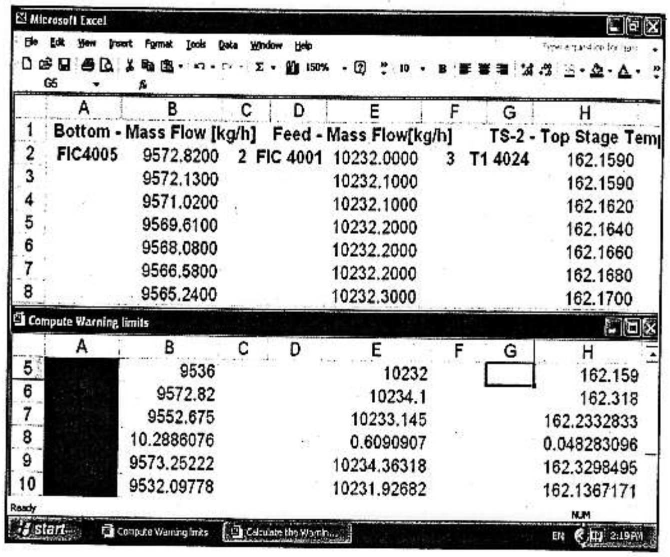

Figure 5 - :Example of Excel Worksheet

Table 2 - Warning Limits

Types of Sensor	Lower	Upper
FIC 4005	9252.14 kg/h	9793.20 kg/h
FIC 4001	9898.12 kg/h	10568.16 kg/h
TI 4024	162.12 °C	162.35 °C
PIC 4001	7.75 kPa	8.02 kPa
FIC 4003	3113.98 kg/h	3114.01 kg/h
FIC 4004	649.77 kg/h	696.98 kg/h
Distillate Composition	0.60 mol fraction	0.53 mol fraction
Bottom Composition	0.51 mol fraction	0.51 mol fraction

Then the warning limits and HAZOP study (Table 1) are written in programming language:

if (Sensor TI4024 >= " 162.35 ")

{ Deviation = "Warning! Sensor TI 4024 - Temperature Getting Higher";
Causes = "Temperature Indicator TI 4002 fails and Heating Medium (TT4402) overheated." ;
Consequences = "Thermal expansion of pipings and Precut column will overheated.";
Action = Check for indicator TI4002 and and verify nitrogen purging into the column."; }

else if (Sensor TI4024 <= "162.1192")

{ Deviation = "Warning! Sensor TI 4024 - Temperature Getting Lower";
Causes = "Partial plug or blockage in pipeline from

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storage to Feed Filter.";
Consequences = " Specification function of recycling part of ejector and pressure level in packed column will be deviated.";
Action = "Check for indicator TI4002."; }

else

{ Deviation= "Normal Condition."; }

Meanwhile, Figure 6 shows the environment of editor area.

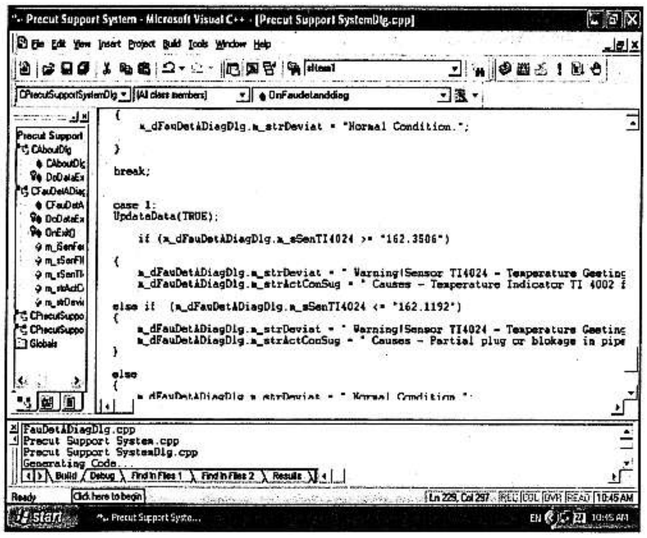

Figure 6 - Environment of Editor Area

Discussion

Figure 7 shows the Fault Detection and Diagnosis (FDD) support system. User needs to select a radio button and insert a value in the edit box. The system will execute and predict the results (i.e. condition of the process, cause, action, consequences and action). If user had selected the radio button of sensor TI 4024 and keyed in a value of 165, then the screen will display out the results as shows in Figure 8. From there, operator or user will know the process conditions and understand the status of the plant. They would not have to waste time to find out the solution.

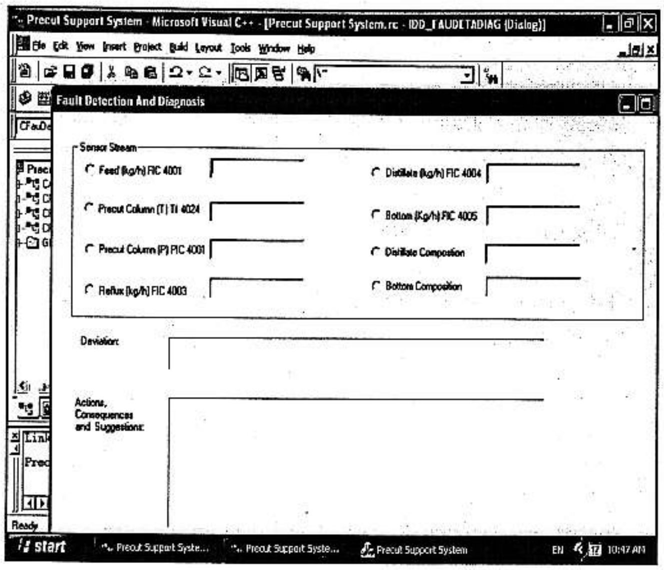

Figure 7 - Created FDD Support System

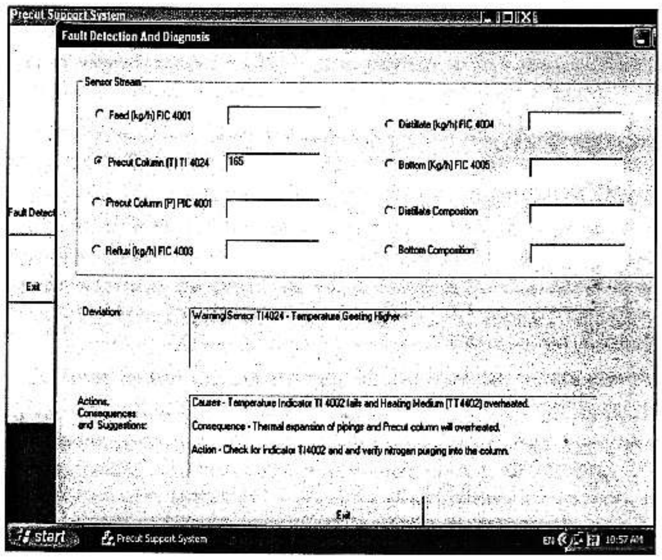

Figure 8 - Result Display on the Screen for Sensor TI 4024

Conclusion

A support system approach to process and sensor fault detection which is based on 2 sigma and identifies the causes and recommendation by using the conventional HAZOP study has been developed. It can be concluded that:

1. The system is able to assist process operator to predict process status if any fault occurred.
2. The system is able to give causes and actions to be taken by the operator in the treatment of process malfunction.
3. Immediate results can be obtained without searching the HAZOP worksheet.

Although the support system should be able to assist a process operator in some way but it still need further improvement to reach the intelligent stochastic systems. The detection part should be made online, where users can easily get the result without manually handling the support system.

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