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Process Monitoring and Analysis of Dynamic Systems for Smart Manufacturing

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Abstract –*Within the realm of smart manufacturing, meticulous monitoring and analysis of manufacturing processes stand as crucial pillars for ensuring product quality, enhancing production efficiency, and curbing defects. This study delves into the realm of process monitoring techniques, focusing on their application to scrutinize and refine the performance of a process control trainer kit utilized within smart manufacturing environments. User-defined design prerequisites were established by individuals engaged in academic, research, and industrial training endeavors within the domain of dynamic systems and process control. These specifications encompass industrial instrumentation, the measurement of controlled and manipulated variables, disturbance monitoring, process reconfigurability, diverse control technologies, varied control strategies, suitable visualization materials, and compact dimensions to optimize laboratory space. The designated process under examination is a tank system offering a spectrum of dynamic behaviors: first, second, and third order dynamics, linear and nonlinear behaviors, and dead time; its associated mathematical model depicting system dynamics is presented. The developed system serves as an educational asset, facilitating industrial training and research endeavors. Moreover, the equipment proves instrumental in the implementation and testing of various advanced control techniques. By amalgamating diverse control strategies, real-time data acquisition, and comprehensive analysis, this investigation seeks to amplify process performance, pinpoint potential sources of variability, and foster continuous enhancement within manufacturing operations*

Keywords- *Smart manufacturing, Process Monitoring, dynamic systems*

I. INTRODUCTION

Over the past few decades, the degree of instrumentation of processing units and general engineering systems, as well as the precision of the sensor data, have improved in response to the requirement for strict process monitoring. The data that is regularly gathered and stored for instance, in engine management systems for internal combustion engines and distributed control systems for chemical manufacturing facilities is compared to scenarios that are considered optimal or usual [1]. Industrial process data are becoming massive and increasingly valuable assets for decision making in process operations, process control and monitoring [7]. Data obtained from process monitoring are generally provided in real time by different univariate sensors (e.g., flow rates, temperatures, pressures, etc.) and stored in extensive databases [9]. The data gathered during normal operation include a lot of valuable information about the ongoing process. Numerous curricula have adeptly integrated conventional teaching methodologies with problem or project-based learning, thereby enabling engineering students to meet contemporary educational standards [2]. These experiences hold significance within dynamic systems and process control education, as they not only facilitate comprehension of fundamental concepts but also bolster essential skills vital for professionals across various disciplines. Active learning methodologies contribute to the acquisition of crucial abilities such as problem-solving, decision-making, teamwork, effective written and verbal communication, and critical thinking [3]. Laboratory set up of Process Control Trainer is a state-of-the-art educational platform designed to showcase a wide array of trials and sophisticated control strategies with diligence-standard instrumentation. With Supervisory Control and Data Acquisition (SCADA) functions, MODBUS communication, and Distributed Control System (DCS). This coach is equipped with homemade and bus tuning functionalities, along with a patch board for configurable trials and external regulator integration. The system includes diaphragm pump with Variable Frequency Drive (VFD), SS wetted parts, and compressor for a comprehensive literacy experience. Configured as a small artificial process factory, the coach employs DCS control with especially developed software. A unique patch board interface facilitates trial configuration, allowing to develop and test their control strategies. With further than 25 experimental configurations, the product covers introductory element studies to complex process control circles. The different modules, including heating tank, control panel, water force, process tanks, flow seeing rudiments are connected on a stage-alone structure. trials cover a range of, from element basics and flow measuring bias to interacting and non-interacting system studies, single-circle feedback control, multi-loop control, and PLC studies. The software module includes control developer and administrative control software, furnishing a user-friendly interface with features like trend plots, data logging, data access publishing, and data import.

Experimental set up stands as a comprehensive and innovative platform designed for educational and practical disquisition of different artificial control ways. The system aims to demonstrate a broad range of trials and operations, exercising assiduity- standard controls and instrumentation. With features like SCADA capabilities, DCS control and MODBUS communication, the coach offers a holistic approach to understanding advanced control methodologies. This compact, yet protean, system resembles a typical small artificial process factory, complete with a range of factors and modules. The DCS control provides a hands- on experience in configuring different trials. The unique jack draw and socket patch board allow druggies to develop and test their control strategies, offering inflexibility in trial. The setup includes MNC- grade regulators and transmitters, with bathe corridor made of artificial- grade pristine sword, icing trust ability in different experimental conditions. The coach boasts further than 25 different configurations, covering everything from introductory element studies to advanced examinations of complex process control circles using sophisticated DCS control. The individual modules, similar as the heating tank module, control panel module, water force module, control stopcock module, process tanks module, flow seeing rudiments, and air force module, each contribute to the comprehensive literacy experience. These modules are mounted on a stage-alone structure and connected with faucets and pipeline, replicating the complications of a real artificial setup. The range of trials spans from the study of element basics, flow measuring bias, interacting and on-interacting system studies, single- circle feedback control, multi-loop control, to the disquisition of (Programmable Logic Controllers) PLCs. Software includes features like data access, trend plots, data logging, publishing, and data import. Through its different range of trials and advanced features, it equips with the demanded to attract real- world challenges in the field of control systems and robotization.

II. THEORETICAL BACKGROUND

In smart manufacturing, with information sharing among different equipment of the same type, it is expected that process monitoring algorithm should be able to predict when the equipment needs maintenance. Under such a predictive maintenance scheme, a maintenance would be performed when it is needed, which could be earlier or later than the fixed preventive maintenance event. With predictive maintenance, one can not only reduce process downtime by eliminating unnecessary maintenance, but also improve process profitability by avoiding catastrophes through detecting potential problems and addressing them in their infant state. To achieve predictive maintenance, information sharing among different piece of equipment, tracking of individual equipment health, and self-adaptive modeling will likely have to come together, in order to achieve optimal decision in real-time [2].

Figure 1 illustrates a general block diagram of process control, which encompasses techniques aimed at regulating process conditions to achieve and sustain desired values while mitigating undesired occurrences. A process typically involves the interaction and transformation of material and energy streams. Examples range from generating steam in a boiler to fractionally distilling crude oil into gas, gasoline, kerosene, gas oil, and residue. Processes also include sintering iron ore and polymerizing propylene molecules to produce polypropylene. Process control, in its comprehensive scope, involves determining optimal values for these processes.

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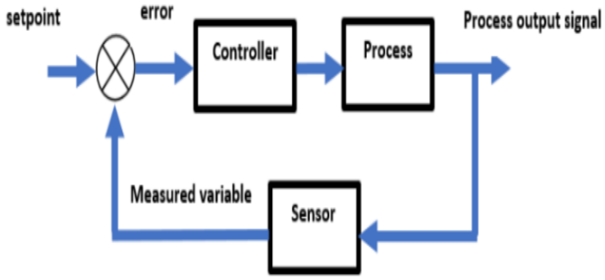

Fig. 1 The general block diagram of process control

III. EXPERIMENTAL SETUP

Table 1- Process components used in the laboratory

Product	Universal Process Control Trainer
Type of control	DCS and SCADA
Control unit	Hybrid controller, Make Honey well, ModelHC900, AI 8, AO 4, DI 16, DO 16, Control loops 8 With
Communication	RS232, RS485, Ethernet
Software package	DCS: Hybrid Control Designer
Temperature sensor	RTD, PT100, Range 0- 100 deg.C, 2Nos
Temperature transmitter	PT100, Type 2 wire, Range 0- 100 deg.C, Output 4-20mA, 2Nos
Flow transmitter	DPT, Type 2 wire, Range 0–200 mmH2O, Output 4–20 mA, Sq. root
Level transmitter	DPT, Type 2 wire, Range 0–500 mmH2O, Output 4–20 mA, Linear
Level transmitter	GPT, Type 2 wire, Range 0–600 mmH2O, Output 4–20 mA
Pressure transmitter	GPT, Type 2 wire, Range 0–2.5 bar, Output 4–20 mA
Position transmitter	Type Electronic, 2 wire, Output 4–20mA
I to P converter	Input 4- 20mA, Output 3- 15 psig (2Nos)
Heating control	Proportional power controller (SSR), Input 4- 20 mA
Heater	Type Electrical 2 coil, Capacity 3 KW
Rotameter	40- 400LPH
Solenoid valves	Type 2/2way normally closed,1/4"BSP, water(2Nos)
Control valve	Type Pneumatic, Size1/2", Input 3–15psig, Linear & Equal % (2Nos)
VFD	Input single phase 200VAC, 1.1A, output AC3 Phase
Pump	Fractional horse power, Type centrifugal
Diaphragm pump	Positive displacement Diaphra pump, Cap 200Lph
Compressor	1 Hp,3.8CFM, 10 kg/cm2 with 45 lit inbuilt tank Receiver
Overall dimensions	1150mmL x 800mmW x 1900mmh

A process control setup is a comprehensive educational tool designed to simulate and teach fundamental concepts of process control and automation in various industries, including manufacturing, chemical processing, and automation engineering. The kit typically consists of hardware components, software interfaces, and instructional materials aimed at providing hands-on experience and theoretical understanding of control systems and processes.

Process simulator unit: This unit serves as the core of the trainer kit and often includes components that mimic real-world industrial processes. It may feature tanks, pumps, valves, heaters, coolers, mixers, reactors, and other equipment necessary for simulating different types of processes such as pressure control, temperature control, flow control and liquid level control.

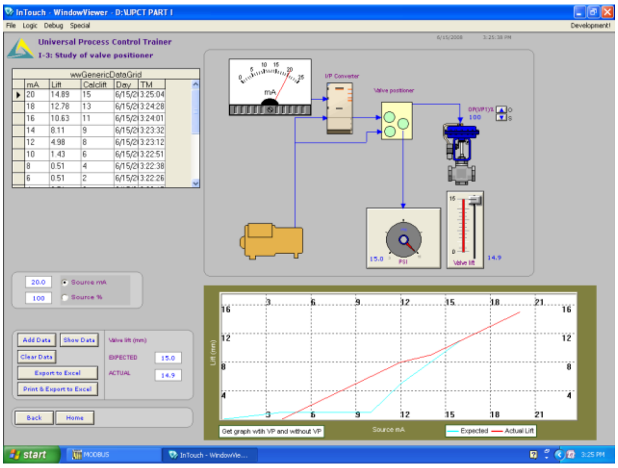

Fig. 2 Expected and actual lift of valve positioner

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Fig. 2 showing the plot of valve positioner lift with respect to the input current. As the current increases from the minimum value of 4 mA to the maximum value of 20 mA, the valve position gradually changes from closed to fully open, allowing for precise control of the process fluid flow.

Control unit and water supply module:

The control unit in a process control trainer kit serves as the central brain that manages and regulates the entire process. It typically consists of a microcontroller or a programmable logic controller (PLC) that executes control algorithms and interfaces with sensors, actuators, and other peripheral devices.

Functions of the control unit may include:

Receiving sensor data: It collects data from various sensors placed within the system, such as temperature sensors, pressure sensors, flow meters, etc.

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Processing data: It analyzes the sensor data and executes control algorithms to make decisions regarding the system operation.

Sending control signals: Based on the processed data and control algorithms, the control unit sends commands to actuators (such as valves, pumps, heaters, etc.) to adjust process variables and maintain desired setpoints.

Interface: It provides interfaces for users to interact with the system, such as displays, input buttons, and communication ports for data logging or external control.

Fig. 3 Control unit and pressure system

The water supply module is a subsystem within the trainer kit responsible for managing the flow, pressure, temperature, and other properties of water within the control system. It typically includes components such as:

Water tanks or reservoirs: These store the water used in the system.

Pumps: They regulate the flow rate of water through the system.

Valves: They control the direction and rate of water flow within pipes and channels.

Sensors: These monitor various parameters like water level, temperature, pressure, etc.

Actuators: Devices like valves and pumps that adjust flow rates and pressures based on control signals from the control unit.

Pipes and fittings: These components form the physical infrastructure through which water flows within the system.

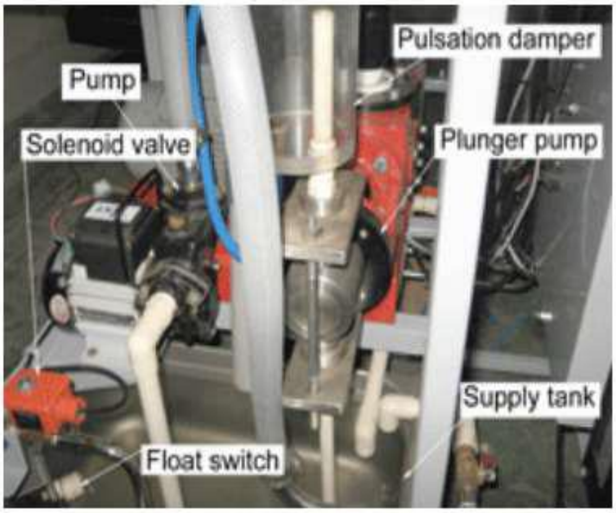

Fig. 4 Water supply module

III. METHODOLOGY

The experiment effectively showcased the I/P converter' functionality by connecting Controller Analog Output no.1 to I/P1 and manipulating valve settings. The resulting graph of Output Pressure versus Source mA revealed a linear relationship, indicating the converter's responsiveness to changes in the input signal. The observed incremental increase in output pressure up to 20 mA provided valuable data points for calibration. Significantly, the experiment underscored the importance of adjusting zero and span settings to ensure the accurate performance of the I/P converter, as evidenced by the linear trend observed in the graph. Furthermore, the experiment demonstrated the adaptability of the setup, with the potential for using an

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external current source at I/P1, enhancing the converter's versatility in various configurations.

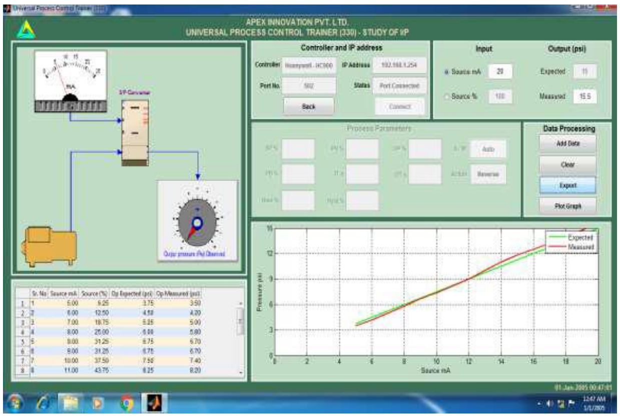

Fig. 5 Software interface of I/P converter.

Design the electronic circuitry for converting the input current signal (4-20 mA) into a proportional pneumatic output pressure signal (3-15 psi). Implement linearization techniques and compensation circuits to ensure accurate and linear conversion across the entire input range. Design appropriate signal conditioning circuits to filter noise and ensure signal integrity.

Developing a Differential Pressure (DP) transmitter involves a systematic methodology to ensure its accuracy, reliability, and compatibility with industrial applications.

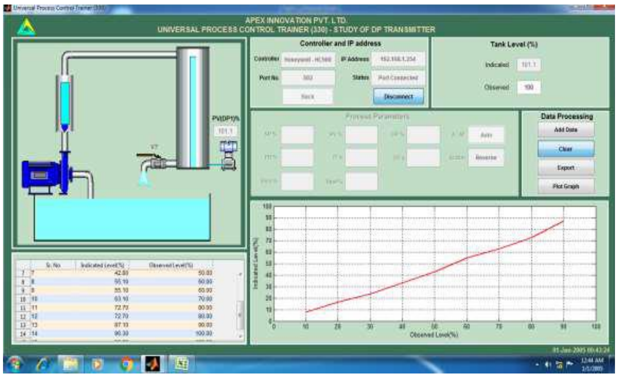

Fig. 6 Software interface of DP transmitter

DP transmitter experiment revealed a linear relationship between indicated and observed tank levels, affirming its accuracy. Pump1 activation, with 10% level increments, yielded corresponding values. Minor discrepancies at full scale were attributed to water temperature or scale markings. The experiment underscored the transmitter's calibration capability via Zero adjustment, ensuring precise level measurements. Furthermore, the use of an milliammeter at the control panel proved effective in validating the DP transmitter's output.

IV. PERFORMANCE EVALUATION OF SYSTEM

The response time of the control valves and actuators was measured under different setpoint changes. The accuracy of the sensors and transmitters was evaluated through calibration tests and comparison with reference standards. Results show that the sensors achieve an accuracy of within +/- 5 % of the measured value, ensuring reliable data acquisition and control. The precision of the control algorithms was assessed by analyzing the deviation between setpoints and actual process parameters. The average deviation was found to be within acceptable limits, indicating precise control.

V. RESULT & DISCUSSION

The process control trainer kit was successfully developed and implemented to simulate various industrial processes and control mechanisms. The kit includes components for flow control, level control, temperature control, and pressure regulation, allowing users to gain hands-on experience in process control and automation.

VI. CONCLUSION AND FUTURE WORK

The process control trainer kit effectively fulfills its objectives of providing hands-on experience in process control and automation. Continuous improvement efforts will further enhance its utility and educational value in preparing students and professionals for careers in industrial automation and control systems engineering. Based on the results and feedback obtained, several areas for future development and enhancement of the process control trainer kit have been identified. Integration of advanced control algorithms such as Model Predictive Control (MPC) and adaptive control. Incorporation of IoT capabilities for remote monitoring and control of processes. Expansion of the kit to include modules for advanced topics such as multivariable control and process optimization.

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