LabVIEW Based Development of a Model for a Special Testing Machine (STM) and Design and Implementation of Fuzzy Based Control System for Natural Gas Pipes

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Abstract

The quality of Natural Gas Piping Systems (NGPS) must be ensured against any manufacturing defects. For this purpose, we develop a special testing machine (STM) constructed at the lab to test (NGPS). The proposed (STM)[1] function is based on testing the weak points at the pipe connections e.g. pipe bends, and intermediate connections. For more than 1500 pieces of (NGPS), crack propagation simultaneously followed up and monitored on the output screen at the critical positions of the pipelines connections. The control system utilizes the LabVIEW™ tools for various signals acquisition and monitoring also for designing the control system strategy.

Keywords: *Natural Gas Piping Systems (NGPS), special testing machine (STM), LabVIEW, hydraulic power cylinder (HPC)*

1. Introduction

Piping systems are like arteries and veins for power plants, oil refineries, petroleum pipelines, cities urbane plan watering and light gas systems and food industry. The natural gas transportation, and distribution pipelines convey natural gas from the source and storage tank to the utilization stations, *e.g.*, power plants, various industrial regions. Pipe bends are considered as the most critical components in piping systems. They are incorporated into piping systems to permit modification of the isometric routing. Furthermore, pipe bends are usually built-in to reduce anchor reactions. Special testing machine (STM) [1] is a unique testing machine which, used to implement all mechanical tests mainly for Natural Gas Piping Systems (NGPS) also, for other types of flat and fracture specimens. STM can perform several tests namely; tension, compression, bending, torsion, fatigue, and combined loading (opening and closing mode) under internal pressure. The other unique feature is related to testing speeds which are about three times compared with other testing machines. The maximum testing speed and maximum span are, V = 6000 [mm/min], and S = 950 [mm] respectively.

2. System Design

STM consists of the following parts; (i) Mainframe which contains fixing accessories for pipes, flat, and fracture specimens, (ii) Hydraulic power unit [2], (iii) Electrical power unit [3], and (iv) Automation unit as shown in Figure 1. The automation unit implements three main tasks; the first task is to control the orientation of the hydraulic power cylinder (HPC) [4, 5, 6] to change the mode of testing. The testing modes depend on the orientation of the acting force on the specimen; for tension or compression mode the acting force must be perpendicular to the specimen surface so that HPC should be oriented vertically as shown in Figure 2.

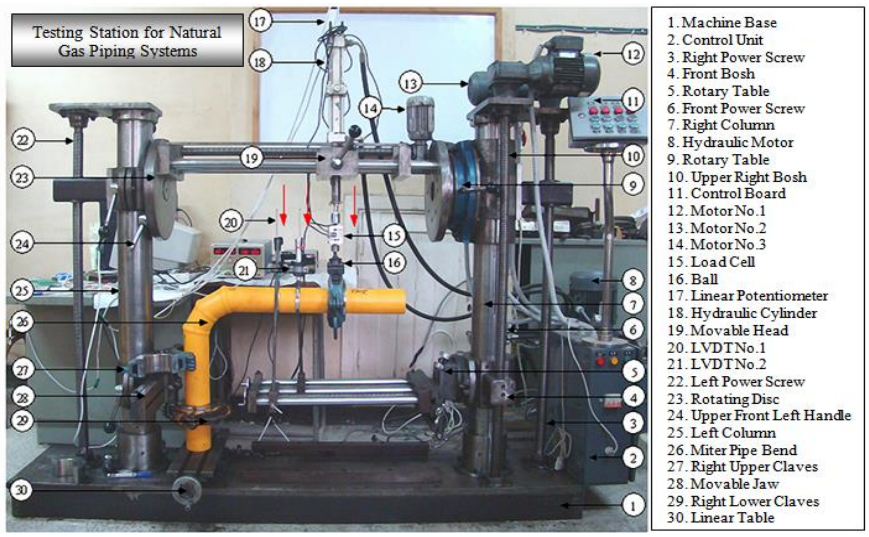


Figure 1. Photo of Testing Machine for Natural Gas Piping Systems (NGPS)

The torsion test needs to rotate HPC around the X-axis (90°) to produce the torsion force (FZ). In case of fatigue test, HPC is oriented to the required loading point after that the fluctuated force acts on the specimen for several cycles. Orientation control involves three electric motors for vertical motion along Y-axis, for horizontal motion along X-axis, and for rotation around X-axis as shown in Figure 2.

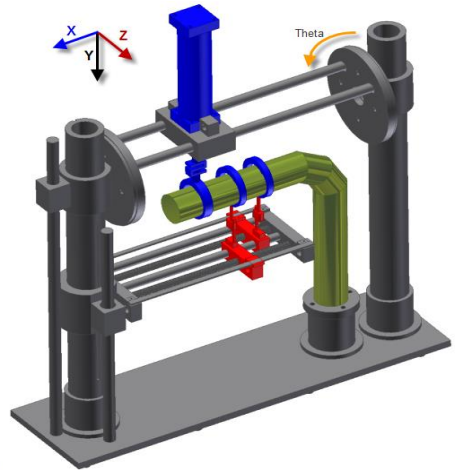


Figure 2. Three Dimensions Model for Special Testing Machine (STM)

The Second task is to control the hydraulic system. The hydraulic system consists of i) Hydraulic service unit including pump, filter and hydraulic safety elements. ii) Hydraulic power cylinder (HPC) which the testing force will be generate on the pipe. iii) Proportional hydraulic valve with embedded power amplifier to control the direction and the speed of the HPC. Integration of different sensors types with up normal environmental conditions requires robust data acquisition card. NI PCI-6221 M series multifunction DAQ (250 k Sample/second, 16 channels 16-Bit Analog Inputs, two 16-bit analog outputs, 24 digital I/O, 32-bit counters) was integrated to the machine control system for more than two years with excellent performance. The DAQ is connected to the hydraulic valve power amplifier through an analog channel. The hydraulic valve receives a signal with ± 10 volt to control the speed of HCP in both directions (positive and negative Y-axis direction).

2.1. Fuzzy Toolkit

The fuzzy toolkit is well suited for control applications on nonlinear or complex dynamics systems such as hydraulic positioning systems.

The dynamic behavior of the hydraulic valve is highly nonlinear along the wide range of speeds therefore; the fuzzy controller is utilized to control the hydraulic valve. Fuzzy controllers generally have many advantages over other controller's types. For example, it does not require a complex mathematical model; also it behaves a good robustness against the system disturbances from the hydraulic elements. National Instrument [7, 8] provides an excellent tool to build the fuzzy controllers. The STM automation is based on the fuzzy controller block witch included in the LabVIEW fuzzy logic toolkit. A fuzzy membership function editor allows to quantitatively defining linguistic terms for input variables with simple GUI interface. First the fuzzification process is entered by selecting the type of membership function for inputs. The inputs are the position error and rate of the position error. The output is the control voltage signal to control the hydraulic valve. Then a rule-base editor is used to define the rules of the controller output based on the linguistic input terms. The fuzzy logic toolkit is used to implement a rule-based feedback controller. Figure 3 shows the block diagram for control loop and signal monitoring loop.

2.2. Block Diagram

The fuzzy logic toolkit is used to implement a rule-based feedback controller. Figure 3 shows the block diagram for control loop and signal monitoring loop.

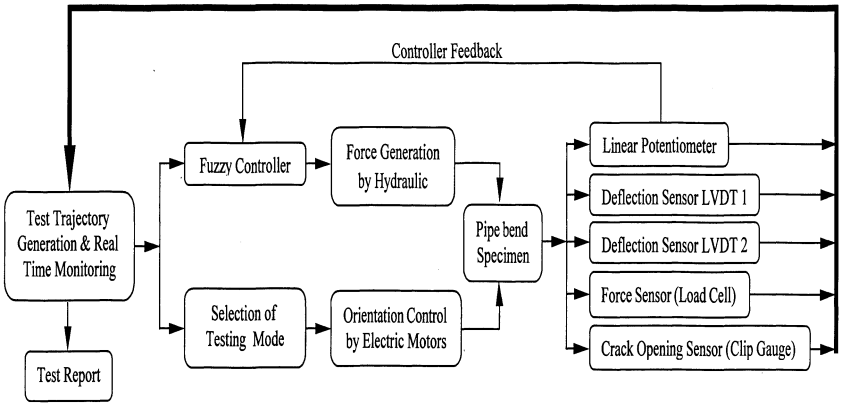


Figure 3. Block Diagram for Control Loop and Signal Monitoring Loop

The third task is to monitor the test signals; during the test many signals from sensors are acquired and monitored as shown in Figure 4, and Figure 5. STM sensors are Precise linear potentiometer (measuring range 600 mm with 0.01 mm resolution) to position the HPC during the test, the potentiometer signal used to control the position of HPC.

Two linear Variable Differential Transformer (LVDT) sensor (Measuring range 100 mm with 0.001 mm resolution) to measure the deflections of the straight pipe specimen at two different loading points. High accuracy load cell with capacity up to one ton (up to 150 % over nominal load) to monitor the applied force (N) from HPC on the pipe bend.

A novel sensor called "Clip Gauge" is designed especially for the machine to measure the crack opening displacement (COD) during the tests with 0.001mm accuracy. Clip gauge sensor is used only for fracture specimens, so that we customize a separate data acquisition card (NI USB 6008) to monitor this special sensor.

3. LabView

LABVIEW (Laboratory Virtual Instrumentation Engineering Workbench) is a development environment [5] that utilizes a graphical programming language, called "G", developed by National Instruments. It is mainly used for data acquisition, instrument control and industrial automation. The LABVIEW program contains tools for acquiring, analyzing, storing and displaying data. Programs created in LABVIEW are called virtual instruments (VIs). VIs are made up of block diagrams and front panels. Block diagrams are where the code is developed and contain all the sub VIs (or subroutines) within the program. The front panel acts like a user interface where the user can input and extract data from the VI.

3.1. NI USB 6009

The NI-USB [7] shown in Figure 4**,** is a module used for data acquisition which can be connected to PC via a USB. It has 8 analog inputs, two analog outputs and 12 digital I/O connections. The module is compatible with programming software LABVIEW.

Figure 4. National Instruments USB 6009

All sensors signals are a real time monitored and plotted such as a special plot for force-deflection curve to characterize the behavior of pipe bend (Elbow) during the test. The natural gas pipes are tested on the STM for characterization and simulation. Characterization involves implementing the standard tests with general loading conditions to the pipes after the manufacturing processes. On the other hand simulation involves implementing special tests with loading conditions that depends to where and how the pipe will be loaded.

3.1.1. Front Panel

Figure 5 shows the Front Panel of the control system

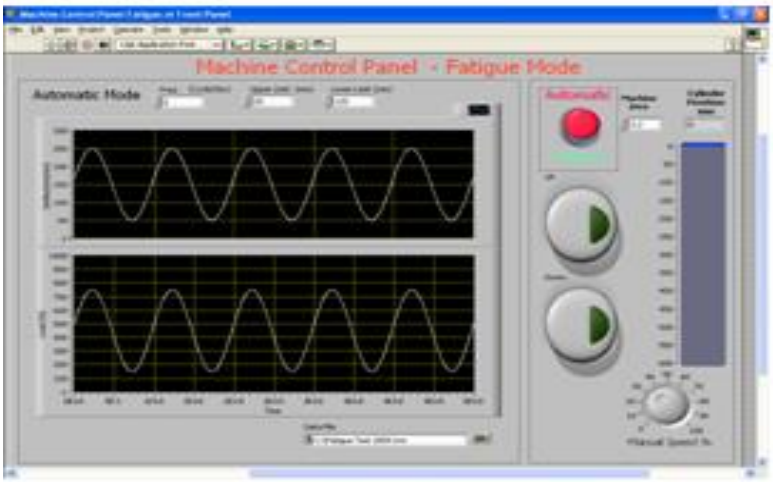


Figure 5. Front Panel for the control system

3.1.2 Block Diagram

Figure 6 shows the block diagram for the control system.

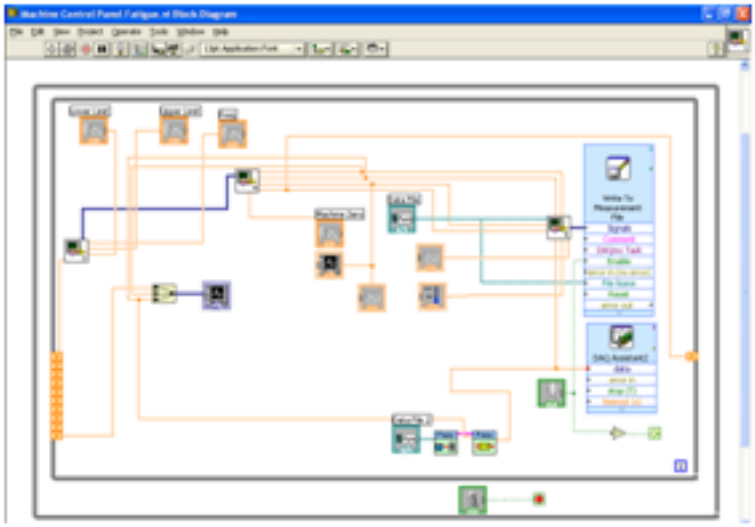
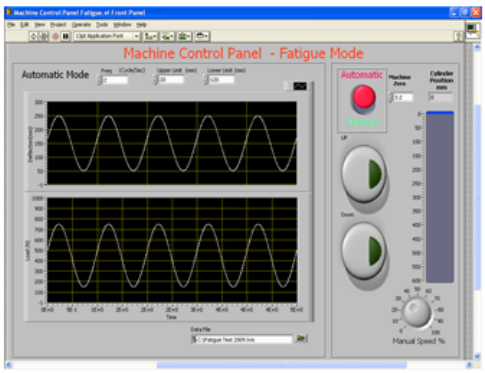


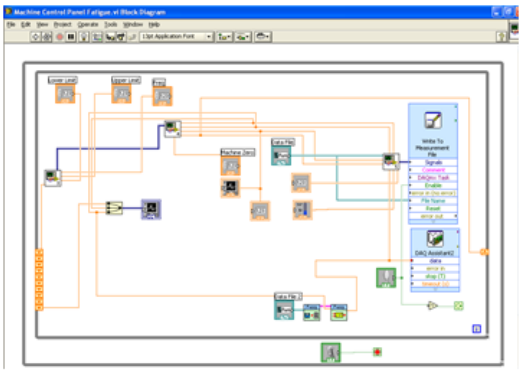
Figure 6. Block diagram for the Control System

4. Results

Above System improves the mechanical testing capabilities and production quality of Natural Gas Piping Systems (NGPS). Current testing rates are insufficient to ensure safety conditions especially for (NGPS). Also, the automation systems for current testing machines are indirectly customized for piping system inspection.



Front Panel for the control system



Block diagram for the control system

5. Conclusions

A novel design of a special testing machine (STM) introduces testing rates three times compared with other testing machines. All tests are implemented in one machine with multifunction monitoring and flexible automation system. The quality of Natural Gas Piping Systems (NGPS) is ensured against any manufacturing defects. For this purpose, we tried to develop a special testing machine (STM) constructed at the lab to test (NGPS). The proposed (STM) function is based on testing the weak points at the pipe connections, *e.g.*, pipe bends, and intermediate connections.

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