



SPE 26220

Fracturing Process Control and Automation: Phase 2

S.V. Stephenson, E.L. Woodall, C.D. Donaghe, and R.E. Dant, Halliburton Services

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This paper was prepared for presentation at the SPE Petroleum Computer Conference held in New Orleans, Louisiana, U.S.A., 11-14 July 1993.

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Abstract

Since the publication of Fracturing Process Control and Automation Phase 1 (SPE 17315), the entire automated and remote controlled fracture stimulation system has been placed into production globally with hundreds of jobs successfully accomplished and documented.

Phase 1 presented the organizational approach to creating the system. Mechanical equipment, computing equipment and software, operating procedures, and documentation requirements were also discussed in the first paper.

Phase 2 of the project involved: (1) a new design concept for a slurry processor, (2) creating software for the central computer in the control and engineering center, and (3) improving the proppant handling equipment. In addition, fluid monitoring systems were developed.

This paper will present the unified automatic fracturing process control system. Comparison of the advantages and disadvantages of automated, semiautomated, and manual systems will be made. The management task for technology transfer from dedicated design team to design and manufacturing staff and from prototype to full production equipment will be examined.

References and illustrations at end of paper.

Introduction

Large fracture stimulation treatments involve a large commitment of resources including personnel, equipment, and time. To get the best results, many operations have to coincide. Traditionally, a frac operator monitored pressure, flow rate, and proppant concentration. If changes were required, verbal instructions were relayed by radio to operators on the various pieces of manually controlled equipment. In 1986, a study was made to determine market needs for fracture stimulation equipment. In-house surveys of field operations, customer surveys, and equipment design surveys revealed the need for improved quality control of the on-site blending process and for better documentation of the treatments.

As noted in SPE 17315, "General design goals for the project to automate and remotely control the fracturing process were to (1) improve execution of complex job design, (2) significantly improve quality control of chemical blends, (3) reduce operational cost, (4) improve safety, (5) provide for changes in job design during progress of the operation, and (6) improve documentation of the processes."

The expertise needed to meet the above-mentioned design goals was in place, but fragmented. The simultaneous engineering concept concentrated the expertise in

one area, with one project, and with one commitment—design an automated and remote-controlled fracture stimulation system. This system provides quality control unattainable by manual control.

Fracturing Process Control and Automation System

The automated control system is comprised of three main categories: (1) electronic components, (2) mechanical components, and (3) data measurement, recording, calculation, and display.

The electronic components include the unit controller, operator interface panel, data communication network, and computer. Considerable emphasis was placed on developing electronic equipment that was rugged enough to survive the oilfield environment.

Mechanical components of the system include mobile proppant storage bins, proppant conveyors, modified blenders, a new concept blender, various pumping units, and the control and engineering center.

Several of the components of the categories were discussed in the SPE 17315 paper. Those components and the modified designs will be briefly discussed. The new concept blender, the software for the control and engineering center, the proppant handling equipment, and the fluid monitoring systems will be discussed in greater detail.

Electronic Components

Three characteristics dictated that the electronic equipment be custom designed: (1) function, (2) environment, and (3) reliability. Each component of the automated and remote-controlled system is equipped with its own unit controller and operator interface panel allowing stand-alone automatic control. The control could be from an operator or from a job management program running in the control and engineering center.

Commercial computers are not designed to withstand the extremes of the oilfield environment. The control computers had to be custom-designed to be mobile and to withstand the extremes of moisture, temperature, and vibration. These custom designed control computers have survived the environmental conditions from the North Slope of Alaska to the deserts of the Middle East, and from the jungles of South America to the North Sea.

Another prime consideration of the electronic equipment was dependable connections between computers and their sensors or control devices. To help guarantee reliable connections, all cables were constructed with molded ends. This not only corrected the problem of broken terminal connections, but also protected the connections from moisture.

All equipment discussed in this paper, as well as the equipment design during Phase 1, uses the same controller card, communication card, and display card. Only the number of controller cards changes, depending on the complexity of the equipment.

Unit Controller

The unit controller is specifically designed to monitor and control functions on each unit. Features of the unit controller include cast aluminum construction, shock-mounted case equipped with heat and humidity controls, and quick-opening lid assembly (Fig. 1). The package is mounted permanently to the unit.

Operator Interface Panel (OIP)

The OIP is housed in a custom-designed, portable enclosure. The OIP can be operated from a local, stationary, control stand or remotely up to 250 ft away. Solidly-mounted internal electronics help endure vibration while traveling or operating. The OIP is shock-mounted on the control stand during transport. To protect the OIP, a special desiccant holder removes moisture from the air as it enters the enclosure.

Data Communications Network

To allow communications between unit controllers, OIPs and the central computer, a local area network (LAN) was implemented. The LAN allows all the data and commands to be available to every unit or piece of equipment on location. While every piece of equipment is automated in its own right, once connected, the frac spread is operated as a system.

Since all data and control commands are sent over the LAN, it is the most critical element of the entire system. Reliability of this critical element is provided by making the LAN a dual token ring. This dual token ring developed for portable, fault tolerant military applications can be characterized as self healing. If connecting cables are cut, signals will automatically be reversed at the terminal nearest the cut, and will be sent to their

destination by travelling in the opposite direction around the ring. If multiple breaks occur, the system will develop local islands of communications between the breaks. Each island will continue to communicate with all other units on the island.

Mechanical Components

Many changes had to be made to traditional fracturing equipment to optimize their performance for automatic control. Some started as clean sheet designs and others were merely modifications of existing equipment. Together, the optimized equipment provides a highly efficient and accurate fracturing process control.

Mobile Proppant Storage Bins

Special features of the new proppant storage bins include: (1) empty bin indicator, (2) controlled flow gates, and (3) bin opening control.

Each of the five compartments in the proppant storage bins has an empty bin indicator. As bins are emptied, the unit controller opens the next gate in the sequence set previously by the operator.

Proppant is discharged from each compartment through controlled flow gates. The controlled flow gates maintain a constant cross-section of proppant on the troughed conveyor belt. The ability of the controlled flow gate to stop proppant flow, while fully open, allows the discharge rate from the storage bin to be varied by adjusting conveyor belt speed. In this configuration, a level control loop adjusts the speed of the belt under the proppant storage bin to maintain a constant level of proppant at the blender's proppant auger hoppers or at the gathering conveyor's hopper.

Previous proppant storage bins had the following disadvantages which were overcome by this design.

- Proppant rate was controlled by running the belt at a constant high rate of speed, and the opening of the gates was varied to control proppant delivery. Either hand signals or radio commands were given to the operator to adjust proppant delivery. This caused a time delay in control since there was no change seen in proppant delivery until the proppant increase at the gate travelled the length of the belt to its discharge.

- With the old hopper discharge design, if the belt stopped, proppant could continue spilling until the bin was empty.
- The old hopper discharge design had a much better chance of spillage which could cause the conveyor belt to lock up and stay stopped until proppant could be dug out from around the tail pulley on the conveyor.

Conveyor

An improved gathering conveyor system accepts proppant from up to nine proppant storage bins and discharges it into the blender. The controlled flow feeding section of the conveyor allows proppant to be placed anywhere on the belt without proppant leaking off.

The proppant is discharged in the same manner as on the proppant storage bin, but the conveyor discharge chute also swings to redirect proppant flow from the main blender to the stand-by blender.

Improvements in the design include an incline of 25° compared to the previous 45° incline. The old system required a pocketed, flexible sidewall belt with cover plates on the incline. This configuration was subject to wear and damage from the idlers at the transition from the flat to the inclined section. More proppant spilled since it had to be confined between the pockets in the belt and the cover plates.

The new design uses a troughed belt with an S-wrap at the transition from the flat to the inclined section. Almost no proppant spills from the new conveyor since the proppant can be transported up a 25° incline without enclosing it.

As discussed in the storage bin section, the conveyor was equipped with an automatic control system to adjust conveyor speed and better control proppant delivery at the proppant auger hoppers.

Blender Retrofitted With Automatic Controls

The retrofitted blender control systems continuously check and adjust the additive rates to maintain precisely a selected ratio between the additives and clean gel. A flowmeter measures the clean gel and speed sensors measure the additive and proppant delivery rates. Control loops proportion the additives and proppant. Suction and discharge pressures, sand concentration

ramps, and tub levels can also be automatic and remotely controlled.

The blender operator has to replenish additives manually as needed and operate manually-actuated valves. If problems develop that cannot be handled automatically, the operator can take manual control of any or all of the control functions.

In a standard blender, only the tub level system was controlled automatically. With so many additives and proppants to control, the manually controlled blender required a highly skilled operator to keep all additives adjusted correctly.

New Concept Blender

The new concept blender departs from traditional blender design. Instead of three engines, a single high horsepower electronically controlled engine and electrohydraulic subsystems are used to power all blending and pumping functions. A patented cylindrical mixing tub was incorporated into the new concept blender to provide better control of the proppant concentration.

Conventional blenders use two different butterfly valves in the tub level control loops to control the tub level at low and high flow rates. A specially designed metering valve with a 100:1 flow range was incorporated into the new concept blender for much better control of the tub level. This equates to better control of proppant concentration.

Use of low-speed, high-torque hydraulic motors and high resolution encoders has allowed the use of a single size proppant auger to control both low and high proppant delivery rates on the new concept blender.

The new concept blender has all of the advantages of the retrofitted blender. In addition, uniquely designed liquid additive tanks are DOT approved for carrying chemicals directly on the blender. Rheology is measured in real-time and tub agitation can be automatically controlled. Previous blender designs required the liquid additive chemicals to be transferred to the wellsite in DOT approved containers and then pumped to the blender before or during the job.

Downhole Pumps

Both existing and newly designed downhole pumping units have been equipped with automatic and remote controls. With the automatic controls, transmission

shifting is automatic. The control system selects the throttle setting and the gear required to obtain a requested flowrate. This shifting arrangement keeps the transmission torque converter in lockup unless a rate gap exists between gears or the unit is running at low engine speeds. Operating in lockup is more efficient, reduces transmission heating problems, and allows precise rate control through all the transmission gears.

An auto rate feature allows the operator to automatically ramp up or ramp down the pump rate to a requested rate. This feature can be overridden or changed during pumping. The auto pressure feature raises or lowers pumping rate to maintain a set pressure. This feature will override the auto rate control if the maximum pressure setpoint is reached before reaching the requested rate. Another safety feature is the pressure kickout setting which automatically shifts the transmission to neutral when its setpoint is reached. This prevents overpressuring the tubing or wellhead.

Only one pumping unit was developed under Phase 1. Today five pumping units are controlled by the ARC system. The pump control program is designed to control any combination of engine, transmission, or pump used. Improved operating interface panels add a strip chart display. The last two minutes of two selected group rates including the maximum pressure is plotted.

On manually controlled downhole pumping units, one operator was required per unit. With the automatic and remote controlled units, one operator can monitor and control, either individually or as an operating group, up to ten pumps from one operator interface panel. The operator can also change between five different operating groups of ten pumps each from the operator interface panel.

Data Measurement, System Output, and Overall Control

Instrument Skid

The instrument skid provides a gathering point for collecting surface data and displaying those data in a useful format. Information collected includes pressures, flows, temperature, and density on pumped-in slurry and gas. This usually provides the last measurement of the slurry before entering the well.

The instrument skid allows monitoring of a slurry flow line, gas flow line, and backside pressure. Optional instrumentation includes a tracer detector for radioactive

treated proppant, a ball injector to allow a programmed ball drop schedule, and an accessory connector for additional data input or output.

Previously, there was no instrument skid. Individual cables had to be run from each transducer to the monitoring van. Problems with portable cables and connectors have been eliminated. A hammerless union was designed for the instrument skid. This union isolates the transducers from direct hammer blows while connecting high pressure lines to the transducers.

Control and Engineering Center

The control and engineering center is the focal point of a frac job. It is from this area that the frac operator monitors and controls the job, the automated equipment, inputs data for the Auto Job Manager, and defines controlling parameters to be used for the various calculations performed in the system.

The control and engineering center monitors over 1,200 surface treatment parameters through the communications network. These parameters consist of rates, pressures, temperatures, densities, material inventories, and equipment status.

All parameters and calculated data are stored on a hard disk during the job. The data sampling rates range from one second for critical parameters to 10 minutes for less critical parameters. If a variable does not change over the sample time interval, the system does not record it until it does change. This conserves disk space, especially while performing job analysis and design during shutdown.

All parameters monitored or calculated by the control and engineering center can be accessed anytime during the job.

The accessed data can be used for job design and analysis programs or displayed by using various printing, plotting, and graphics routines. Graphics routines include the following: CRT strip chart plot, CRT numeric display, log/log plot, KY plot, and design and analysis programs output.

The central data processing and control center has many improvements over the old system. The hardware consists of a 32-bit computer with a 6-pen plotter, a multi-mode printer, and three color monitors. This system replaces a smaller computer with a 6- or 2-pen plotter, thermal paper printers, and two color monitors.

Other improvements include a list of all changes of all parameters made during the job automatically used in playback and job recalculation modes. The control and engineering center uses a series of data entry panels and menus structured in a tree structure of overlapping windows. This compares with the old system, which used a series of questions in a conversation format. The center also provides (1) improved data entry error checking capability, (2) direct screen access from any screen allowing for rapid data modifications during the job, (3) generation of an IBM PC-compatible disk without connection to an IBM PC, and (4) transmission of job data via modem to a remote location while job is in process.

Simultaneous Engineering

A design team was organized with members from various departments of Research and Engineering. This team was moved to a module of the Halliburton Services Research Center. To isolate all members from previous commitments, all of their projects were reassigned to other engineers and scientists. The team members phone numbers were also changed to eliminate distractions from field inquiries and from vendors.

All team members were removed from the authority of previous supervision and told to forget anything previous management had told them would not work or anything they were not allowed to try. The only criteria given was that the designed system was to "work." This removed any design prejudices which had been imposed on previous projects. The team was managed by a project leader through three team members individually overlooking the electronics design, equipment design, and software design.

To ensure that the final designs would fully meet the needs of our operations, four Halliburton field personnel were advisors to the project. These advisors were from different areas of operations to allow the designs to meet as many of the needs of different areas as possible.

To meet a tight design schedule, all engineering had to occur simultaneously. With all designers in adjacent offices in the Research Center, a design change by one member immediately could be relayed to all other designers to ensure that the design would not adversely affect another member's design. There were no formal design reviews since all members were working so closely. Formal design reviews would have taken too much time. The team members from the Engineering

Development and Design Department were extremely familiar with Halliburton's manufacturing system, which enabled the designs to be ready for manufacturing as soon as drawings were finished.

The core group of designers who had been with the project from the start were temporarily assigned to the Engineering Development and Design Department at the end of the project. This provided for technology transfer to the individuals in Engineering who would be supporting the equipment when it went into production.

Conclusions

From the advantages listed for each piece of automated equipment, it is evident that automatic control can be equated to improved quality control. With automatic controls that monitor and adjust the equipment, much higher quality can be obtained than with an operator manually making adjustments. Automatic controls minimize the chance of operator error since the operator only enters setpoints and there is error checking to ensure that the operator entries are valid.

Because of a mix of automatically and manually controlled equipment being possible on a job, a major requirement for automated and remote-controlled equipment is the ability to operate as a stand-alone system. Each piece of stand-alone automated equipment can improve the quality performance by itself with additional quality improvement possible with each piece of automatically controlled equipment.

Acknowledgments

The authors thank the management of Halliburton Services for their support in this effort and for permission to prepare and present this paper.

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