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Report Title: **Downhole Power Generation and Wireless Communications for Intelligent Completions Applications**

Type of Report: Quarterly Progress Report

Project Report Period: Start Date – April 01, 2003
End Date- June 30, 2003

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Date Report was issued: July 05, 2003

DoE Cooperative Agreement No. DE-FC26-02NT41601

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Abstract

The third quarter of the project was dedicated to creating the detailed design for the manufacturing of the mechanical system for wireless communications and the power generation module. Another emphasis for the quarter was the development of the surface system and acoustic detector for the downhole tool for 2 way communications.

The tasks accomplished during this report period were:

1. All detailed drawings for manufacturing of the wireless communications gauge and power generator were completed and the drawings were forward to a machine shop for manufacturing.
2. The power generator was incorporated to the mandrel of the wireless gauge reducing the length of the tool by 25% and manufacturing cost by about 35%.
3. The new piezoelectric acoustic generator was manufactured successfully and it was delivered during this quarter. The assembly provides a new technique to manufacture large diameter piezoelectric based acoustic generators.
4. The acoustic two-way communications development progressed significantly. The real time firmware for the surface system was developed and the processor was able to detect and process the data frame transmitted from downhole. The analog section of the tool was also developed and it is being tested for filtering capabilities and signal detection and amplification.

5. The new transformer to drive the piezoelectric wafer assembly was designed and manufactured. The transformer has been received and it will go through testing and evaluation during the next quarter.

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Introduction

The Downhole Power Generation and Wireless Communications for Intellligent Completions Application project progressed significantly during the April 03 - June 03 report period. The goals for this period were to create the detailed drawings required to manufacture the systems, continue to develop the firmware for the data acquisition and processing software as well as the communications from the surface to downhole. The design for the power generator was also a priority including the type of coating required to prevent erosion of the piezos while in the downhole flow stream. The entire wireless gauge and power generator detailed design was completed and turned over to a machine shop for manufacturing of the system. The wireless gauge and power generator designs were combined into a single tool to decrease the cost, improve reliability and decrease assembly time. A new epoxy powder bonding was found that can be applied to the power generator hardware located on the flow stream to prevent erosion and damage to the hardware. The cold epoxy application will prevent the piezoelectric wafers from being damaged due to high temperature exposure normally required during the application of coatings.

The acoustic two-way communications software was developed and completed during this report period. The transmission frequencies to be used for the acoustic communications through the production tubing were evaluated using 200 ft of 4 ½ inch tubing with an acoustic generator on one end of the tubing and the acoustic receiver at the other end. The tests were performed at the Halliburton facility in Carrollton, Texas. The goal of the test was to find the frequency range with the lowest acoustic attenuation through the tubing. An analog filter/amplifier required to receive and process the raw electrical signal converted from the acoustic information transmitted from the surface was built and tested in conjunction with a new piezoelectric accelerometer used to pick up the acoustic signal at the surface. The analog circuit worked well and will be used both at the surface and downhole.

Executive Summary

The highlights of the accomplishments for this report period are listed below.

1. Detailed mechanical design for the wireless communications system mandrel was created and the drawings were given to a machine shop for manufacturing. The new system has a 3.3 inches Internal Diameter and 6.75 inches Outside Diameter for the wireless gauge section of the tool and an OD of 8.2 inches at the power generation section to provide the external pressure ratings required for burst and collapse in downhole applications. The tool will have 2 pressure sensors and 1 temperature sensor. The thread connections will be new Vamm normally used in deep well applications. The hardware is expected to be delivered by the end of July.
2. The power generator was designed to provide a direct action between the wellbore fluid flow and the piezoelectric stack to generate energy. The new design eliminates the inefficiencies related to picking up outside the tubing wall the pressure fluctuations occurring inside the tubing walls. The piezoelectric assemblies are mounted on the inside of the tubing and the assemblies are exposed to the hydrostatic pressure in the well. A ceramic coating will be used to coat the assembly to prevent erosion as the hydrocarbons flow by the piezoelectric assembly.
3. A new pressure sensor has been purchased that will use a ceramic diaphragm to sense pressure. The new technology will allow the gauge to be calibrated for temperature in the factory prior to shipment to Tubel Technologies. The system will be better shock and vibration mounted to withstand the wellbore environment.
4. The new piezoelectric acoustic generator has been received from the manufacturer. The system will have a 4.588 inches ID and 5.138 inches OD with a length of 7.67 inches. The piezoelectric acoustic generator has 2 brass pieces located at the end of the piezo stack to match the piezoelectric stack temperature coefficient of expansion to the tool material.
5. The acoustic two-way communications software and hardware development progressed well. The software was designed and tested to handle an interrupt to indicate that there is data being transmitted from the surface and decode that information. The hardware to detect the acoustic signals transmitted from the surface was also designed and tested. The hardware uses a piezoelectric based accelerometer that does need any power to pick up the acoustic information and convert it into electrical pulses.
6. The electrical hardware development required to transmit information to the surface and to receive commands from the surface was started. An analog filter/amplifier was built and tested to receive and process the raw electrical signal converted from the acoustic information transmitted from

the surface. An amplifier to condition the signal from the piezo accelerometer was also tested successfully.

7. A new board based on the Intel 386 microprocessor was purchased to provide the data processing at the surface for the acoustic information transmitted from downhole. The board will be interfaced with an analog processing board, LCD display, and 4-20 milli Amperes output to create a complete surface system for data storage and display. The surface system will have a programmable 8 pole bandpass filter and a variable gain amplifier that will be controlled from the PC that were tested successfully.
8. The toroid based transformer design was replaced with a split core transformer that provided a higher magnetic flux to drive the piezoelectric assembly.

Experimental

Experimental Apparatus –An experimental apparatus was created to determine the best frequency for transmission of the acoustic data through the 4 ½ inch production tubing. Two tests were performed to determine the acoustic losses through pipe at the Halliburton facility in Carrollton, Texas. The apparatus was composed of 4 sections of 30 ft, 4 ½ inch diameter tubing was assembled together and attached to an acoustic generator at one end of the pipe and an acoustic receiver at the other end. The other test was performed with 1,000 ft of 3 ½ inch tubing.

The acoustic generator was attached to a frequency generator that allowed different frequencies to be created and transmitted through the pipe. The receiver was composed of a module that housed an accelerometer and the output of the accelerometer was attached to oscilloscope to measure the output voltage equivalent to the acoustic signal level.

The main purpose of the experiment was to determine the behavior of the acoustic signals at multiple frequencies to minimize the acoustic losses as the signals travel through the pipe.

Experimental and Operating Data - The approximate voltage measurements at the output of the receiver accelerometer as a function of the acoustic frequency were as following:

3 ½ inch, 1000 ft of tubing

Acoustic Frequency (Hz)	Accelerometer Receiver Output (milli Volts)
1000	330
975	288
950	380
925	396
900	792
875	608
850	400
825	408

800	256
775	202
750	160
725	140
700	344
675	120
650	102
625	86
600	112
575	200
550	196
525	92
500	124
475	284
450	404
425	212
400	128
375	184
350	124
325	88
300	204
275	204
250	88
225	106
200	106

4 ½ inch 200 ft of production tubing

Frequency	Voltage (Volts)
1000	7.2
800	8.2
600	5.8
400	6.4
200	4.4
250	4.8
300	6.6
350	5.2
450	6.6
500	7.0
550	8.2
100	4.0

The results indicated that there was a significant amount of energy measured at the receiver when the frequency was at around 800 Hz both at the 3 ½ and 4 ½ inch tubing. The results also indicated that there were lower losses at 550 Hz at both pipes. Based on the results a 525 to 575 Hz sweep will be used for the transmission frequencies for the acoustic signals.

Results and Discussion

The wireless gauge and power generation system mechanical drawings have been sent to be manufactured to achieve the goals set for the project. The mechanical detailed drawings were completed and the tool mandrel should be received by the end of July. The system will be manufactured using 4140 steel L80 material strength that can be used in pressures of up to 15,000 psi. A set of springs has been added to the piezoelectric mechanical housing to allow the compression or tension of the tubing while maintaining the piezo assembly compression force constant.

The design of the power generator was modified to be part of the wireless gauge mandrel to reduce the length and cost and to increase the reliability of the system. The power generator was design to provide a direct action between the wellbore fluid flow and the piezoelectric stack to generate energy. The new design eliminates the inefficiencies related to picking up outside the tubing wall the pressure fluctuations occurring inside the tubing walls. The piezoelectric assemblies are mounted on the inside of the tubing and the assemblies are exposed to the hydrostatic pressure in the well. A ceramic coating will be used to coat the assembly to prevent erosion as the hydrocarbons flow by the piezo assembly. The new ceramic coating application to the piezoelectric assembly will be performed at room temperature which eliminates the concerns and problems related to applying coatings at extremely high temperatures that could damage the piezoelectric wafers.

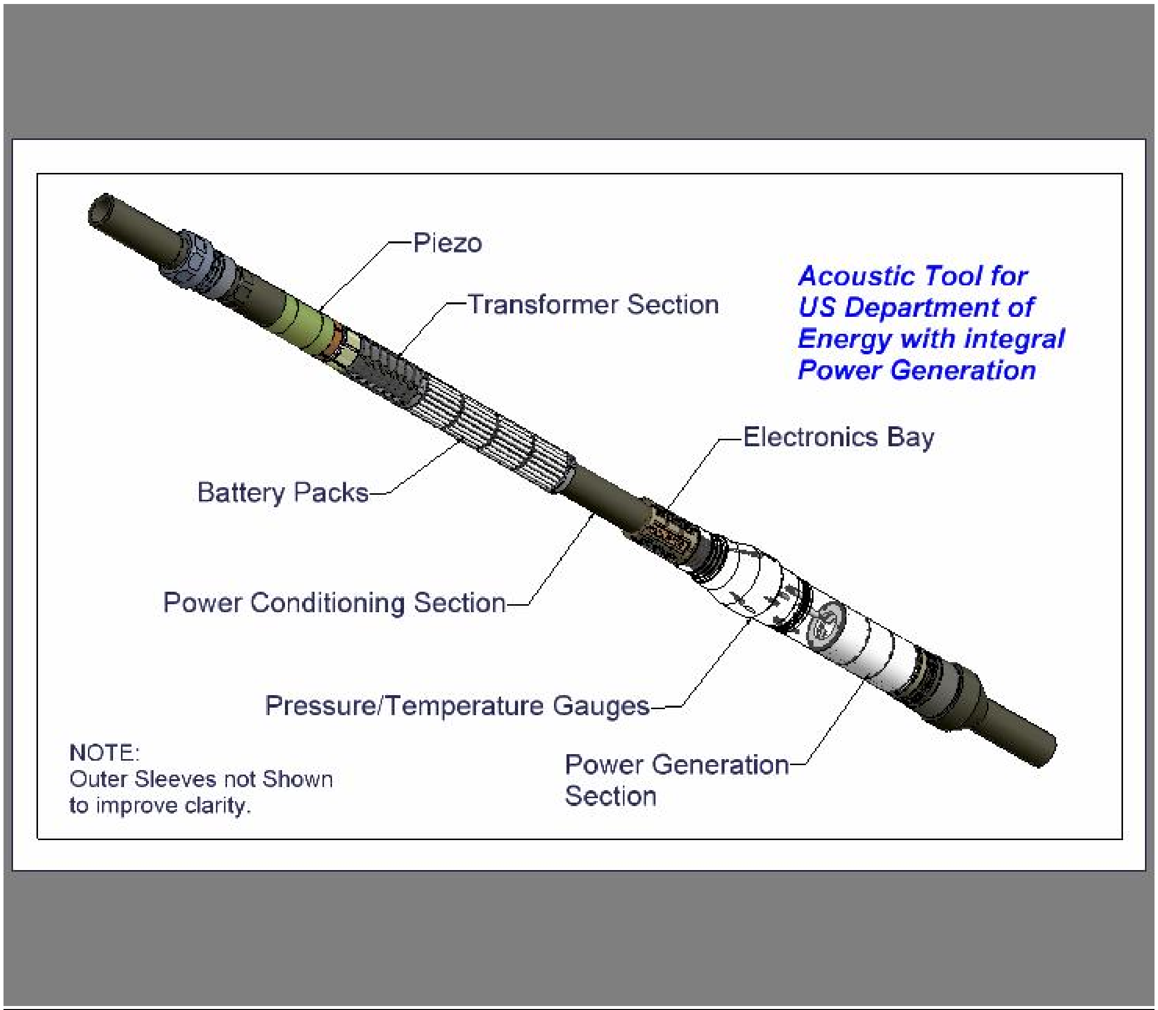

Figure 1 Wireless Communications based Downhole Gauge with Power Generator

The acoustic generator piezoelectric wafers have been designed, manufactured and delivered. The generator uses a new technique to create a large diameter 5 ½ inch diameter wafers. The transformers using small toroids connected in series and parallel for the input and output respectively, did not work as expected and were not able to drive the piezoelectric wafers at the required frequencies. A new transformer design was created and the transformer has been built and delivered to us.

The mandrel was also modified from its original design to eliminate the metal to metal seals and replace them with o'rings. The modifications will provide a better design that will be lower cost and easier to manufacture.

The surface system and downhole receiver modules will utilize the same hardware design composed of an acoustic detector, analog bandpass filter and amplifier. The amplifier and filter will be computer controlled for the determination of the best parameters for the acoustic signal detected by the circuit. The filter is an 8 pole bandpass filter that will attenuate all frequencies except between 525 Hz and 575 Hz. The analog circuits were tested successfully for proper filtering and amplification of the signals transmitted by the downhole tool.

The new software will provide 2 way communications control and processing. Three processors will be used inside the tool to perform the functions required for proper operation of the system. The main processor software will collect data from the sensors, configure the information for transmission to the surface and create the frame for transmission of the data to the surface. The second processor software generates the timing required to wakeup the system and to tell the main processor what task to perform. The third processor receives the data from the surface and configures the data to transfer to the main processor for processing. All data transfer inside the tool is performed using I^2C serial bus. The software uses multiple, nested state machines to acquire and process the data. Also, multiple levels of interrupts are used to provide the proper priority for the tasks to be performed. The firmware code design has been completed and it is now being integrated and system tested.

Conclusion

The conclusions for the first quarter for this project are as following:

- The mechanical design for the wireless gauge and downhole power generator has been completed. The power generator has been integrated to the wireless gauge mandrel to reduce cost and to increase the reliability of the system.
- The mechanical detailed parts have been completed and all drawings have been delivered to a machine shop for manufacturing.
- The downhole and surface acoustic detector and decoder has been developed, assembled and it is being tested
- The software for the transmission and reception of 2 way communications has been developed and it is being system tested.
- The new toroid based transformer had a problem related to power deliver to the piezoelectric module and had to be redesigned. The new design uses a transformer with a split core for mounting the transformer to the mandrel. The transformer will be tested during the July.
- The piezoelectric assembly for the generation of the acoustic signal has been developed, manufactured and delivered to Tubel Technologies. The assembly is being tested.
- The complete tool should be assembled for system testing in mid August.

References

There are no references related to this project and work performed over the past 3 months.

Bibliography

There is no bibliography related to the work being performed.

List of Acronyms and Abbreviations

There are no acronyms or abbreviations in this report.

Appendices

No appendices.