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Development of a Near-Bit MWD System

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CONTRACT INFORMATION

Contract Number	DE-AC21-93MC29252
Contractor	Maurer Engineering Inc. 2916 West T.C. Jester Houston, Texas 77018-7098 (713) 683-8227 (telephone) (713) 683-6418 (telefax)
Other Funding Sources	None
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Principal Investigators	William J. McDonald, Ph.D. Gerard T. Pittard
METC Project Manager	Al Yost
Period of Performance	September 30, 1993 to August 30, 1995

Schedule and Milestones:

TASKS	0												FY95											
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S
1. Define System Requirements	x	x	m																					
2. System Electronic & Mechanical Designs			x	x	x	m																		
3. Fabrication of Near-Bit MWD Prototype						x	x	m																
4. Conduct Laboratory Performance Tests								x	x	x	x	x	m											
5. Phase 1 Final Report													x	x	m									
6. Develop Commercial Sensor Suite															x	x	x	x	m					
7. Shock & Vibration Testing																		x	x	x	m			
8. Fabrication & Testing of Field Prototypes																				x	x	x	m	
9. Implement Design Changes																						x	x	
10. Phase 2 Final Report																						x	x	m

Development of a Near-Bit MWD System

OBJECTIVES:

The project objective is to develop a measurements-while-drilling (MWD) module that provides real-time reports of drilling conditions at the bit. The module is to support multiple types of sensors and to sample and encode their outputs in digital form under microprocessor control. The assembled message is to be electromagnetically transmitted along the drill string back to its associated receiver located in a collar typically 50 - 100 feet above the bit. The receiver demodulates the transmitted message and passes it data to the third party wireline or MWD telemetry system for relay to the surface. The collar also houses the conventional MWD or wireline probe assembly.

The completed Phase 1 program began with the preparation of detailed performance specifications and ended with the design, fabrication and testing of a functioning prototype. The prototype was sized for operation with 6-3/4-inch multi-lobe mud motors due to the widespread use of this size motor in horizontal and directional drilling applications. The Phase 1 prototype provided inclination, temperature and pressure information.

The Phase 2 program objective is to expand the current sensor suite to include at least one type of formation evaluation measurement, such as formation resistivity or natural gamma ray. The Near-Bit system will be subjected to a vigorous series of shock and vibration tests followed by field testing to ensure it possesses the reliability and performance required for commercial success.

BACKGROUND INFORMATION:

The Near-Bit MWD project was initiated following an unsolicit ed proposal submitted to the Department of Energy's Morgantown Energy Technology Center by Maurer Engineering Inc. and Guided Boring Systems, Inc. The proposed development effort addresses a significant opportunity to improve oil and gas extraction from underground formations as a result of more accurate and timely information of bottom-hole conditions being provided to personnel on the rig floor by the Near-Bit MWD technology.

The need for a Near-Bit MWD system is the direct result of the success of directional drilling in general, and horizontal drilling in particular, in increasing both production rates and ultimate recoveries in challenging formations and in mitigating production problems such as water coning and excessive sand production.

Correspondingly, as horizontal drilling technology has improved through evolution, the lengths of deviated sections have grown longer and the range of applications broadened. This has made the need for more accurate well placement more critical. The reliance on obtaining directional data and formation properties some 50 to 100 feet behind the bit becomes progressively less acceptable as turning radii decrease and target formations become thinner. This is because the impact of standoff distance, namely examining what has occurred instead of what is now transpiring at the bit, can result in missing thin targets, falling outside of productive seams or dipping into the water or gas cap. Necessary corrections may entail significant costs such as plugging back and redrilling the bottom portion of the hole. Combined inclination and formation data obtained directly at the bit eliminates these problems - allowing placement of the well to be optimized. Optimized well placement will in turn result in lower drilling and production costs. The R&D program therefore fits well with DOE's mission to improve the nation's oil and gas recoveries.

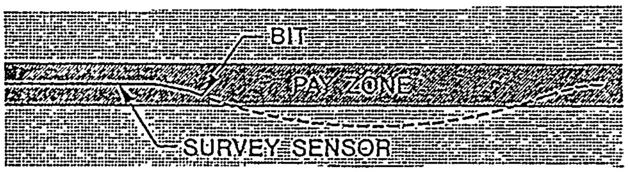

Figure 1. Guidance Problems from MWD-to-Drill Bit Standoff

PROJECT DESCRIPTION:

The Phase 1 project first focused on establishing the performance and operating specifications of the Near-Bit MWD module. The environmental specifications were selected to satisfy the more strenuous loading conditions found at the drill bit while the sensor performance ratings were compared to those for existing commercial MWD and steering tool systems to assure they represented the current state-of-the-art. The industry's preference concerning the informational content and features the Near-Bit MWD system should possess were also tabulated and used to prioritize sensor development to assure inclusion of the most beneficial sensors first.

Interface protocols employed by various MWD and wireline steering tool manufacturers were identified and used to prepare the specifications of the receiver-to-host communications. As with the other specifications, they were thoroughly reviewed since they formed the basis for the follow on design activities.

The detailed design effort had the goal of producing a prototype unit which had the required form and functionality suitable for downhole operation. Design efforts were separated into mechanical and electronic elements.

The Near-Bit mechanical housings were designed to afford maximum protection to the electronics and downhole batteries. Several shock mounting and vibration damping techniques were evaluated along with alternative methods of PCB board fabrication and component options to provide reliable operation under the higher levels of loading that will be experienced from the system's placement in direct proximity to the drill bit. Substantial use of multi-chip modules, surface mount technologies and special stress bars were employed to extend the system's mean-time before failure.

Apart from the survivability of the Near-Bit module, the overall sub length was to be kept as small as possible to minimize the increase in bending moment on the Moineau motor bearing packs and its effect on steering response.

The mechanical housing was also designed to exceed the torque and overpull ratings of the drill motors with which they would be used. Flow areas were maximized to minimize pressure drops and support the passage of lost circulation materials.

The electric impedance properties of the drill string-earth-drilling fluid environment were bounded and applied to our understanding of EM signal propagation to define the most effect means of transmitting data from the bit sub to the drill collar containing the Near-Bit receiver.

The completed designs were then used to fabricate and assemble a complete Near-Bit MWD module plus one set of spare parts. The unit was then subjected to laboratory testing of its range under various simulated borehole environments and for its reliability under vibrational loads.

RESULTS:

Phase 1 Project (Complete)

Technical specifications of commercial MWD and wireline steering tools were examined in terms of sensor measurement accuracies, pressure and temperature ratings and operating life. The collected information was then used to establish the performance specifications of the prototype Near-Bit MWD sensor and support electronics. These specifications are listed in Table 1. Maximum overpull and torsional load carrying capacities of standard drill collar/mud motor combinations were then applied along with maximum borehole pressure and temperature ratings to specify properties of the mechanical housings whose primary function is to provide protection to the electronics and to transmit/react drilling loads.

The above process resulted in the detailed design and fabrication of a 6-3/4-inch Near-Bit MWD prototype shown in Figures 2 - 5. Referring to Figures 2 and 3, the device operates as follows:

1. The control program residing in EEPROM of the downhole processor periodically collects the tri-axes accelerometer, temperature and pressure sensor data via its multiplexed A/D convertor. The operating software was prepared so that all aspects of the data collection process can be adjusted under operator control.

2. The collected sensor data along with the system status information is assembled by the microprocessor into a digitally formatted message string.

3. The message string is then digitally impressed onto the drill string using the high power transmitter circuit. The transmitter employs frequency shift key encoding and features a wide dynamic range from low, near-DC frequencies to frequencies in excess of 50 kHz. As with the message string length and content, the transmission trigger, message repetition and duration are fully programmable.

4. The transmitted message is received by the receiver-demodulator located in a standard drill collar placed up to 100 feet above the Near-Bit MWD sensor/transmitter sub. The receiver decodes the message and is designed to pass the data elements to a third party MWD or wireline host for integration and subsequent transmission to the surface. To maximize communication flexibility, the project team designed the Near-Bit MWD receiver to support data transfer to the host as either a fully buffered digital or analog message.

5. Operating power for the both the Near-Bit sensor/transmitter sub and the receiver are supplied by on-board battery packs. Rechargeable nickel-cadmium and lithium batteries are both supported depending upon the borehole temperatures to be encountered.

The Near-Bit MWD mechanical sub, shown in Figures 4 and 5, employs a coaxial design in which the sensors, electronics and batteries are mounted to a specially machined mandrel. The batteries are mounted on the inside of the mandrel while the sensor and support electronics are mounted on the mandrel's periphery. Proprietary shock mounts and full potting are employed to protect against possible damage during operation. The mandrel is keyed to the lower bit box assembly using two, high precision keys. This assures fixed orientation of the sensors on assembly. A steel pressure housing screws onto the bit box housing and provides a lower seal, This is followed by placement of a threaded cap on the top of the pressure which completes the pressure-tight seal of the electronics from the pressurized drilling fluid. Start up, reprogramming and battery charging can be accomplished by removing an access cap which covers a high pressure, multi-pin connector.

An outer housing is also threaded onto the lower bit box. Its function is as a mechanically robust member for transmitting loads between the drill motor and the drill bit. Inspection of the overall design shows that no drilling loads are directly carried by the instrumentation housing.

Table 1. Preliminary Near-Bit MWD Specifications

MECHANICAL	
Sub Diameter	6.750 Inches
Sub Length	34 Inches Assembled
Flow Area	7.85 Square Inches
Over Pull Capacity	>200,000 Lb
Pressure Rating	15,000 psi
Material of Construction	4140 CHT
Tool Joints	41/2 API Reg. Pin x 41/2 API Reg. Box (down)
SENSORY	
Type of Sensor Data:	
Triaxial Acceleration	+/- 1g Range
Inclination	0.1 Degrees Accuracy
Temperature	125 Degrees C
Pressure	15,000 psi
COMMUNICATIONS	
Telemetry	EM Frequency Shift Keying
Transmit Frequencies	Selectable
Baud Rate	Selectable
Transmission Trigger	Stop pumps (Stop Rotation)
Near-Bit to Conventional MWD Data Transfer	RS-232, Parallel and Analog Transfer
OTHER	
Power Source	Lithium or Ni-Cad Batteries
Operating Life	200 Hours
Lost Circulation Materials	Pass
Retrieval	Overshot

The drilling fluid exiting the motor travels through the annulus formed between the outside diameter of the inner pressure barrel and the inside diameter of the outer load bearing housing. The area of the annulus is almost 8 square inches - minimizing pressure drop across the sub.

Prototype Testing

Following assembly and calibration, the Near-Bit prototype was subjected to a series of performance and reliability tests. The performance tests examined the ability of the EM telemetry link to transmit error free data across a 100 ft. Transmitter-to-Receiver separation distance. Tests were performed which simulated both mud- and air-drilled boreholes. In addition, several different methods of signal coupling were investigated; including direct and capacitive coupling.

Of the signal coupling methods investigated, direct signal coupling provided superior signal-to-noise ratios and worked in both borehole extremes. The tests further validated the performance of the automatic gain control circuit to prevent saturation in drilling environments which are only weak attenuators and to provide the required signal amplification in the other extreme of either highly attenuating mud-borehole combinations (low AC drive impedance.)

The Near-Bit sensors and electronics were also assessed on the ability of the prototype design to successfully withstand vibrations. The prototype was placed on a shake table and tested for 50 hours at a frequency of 5 hertz followed by 100 hours at 10 Hertz. The probe was fully powered throughout all these tests and the transmit trigger was deactivated in place of a sending a complete message once every 3 seconds. Data was received by the receiver which in turn periodically recorded the data to diskette. The message data was examined and the unit's pre- and post-test calibration constants examined for change.

The unit was also disassembled and visually inspected for damage upon completion of the 150 hour test cycle. No change in the calibration constants, fall off in performance or component damage were observed. While more strenuous testing will obviously be required in Phase 2, the results were quite promising.

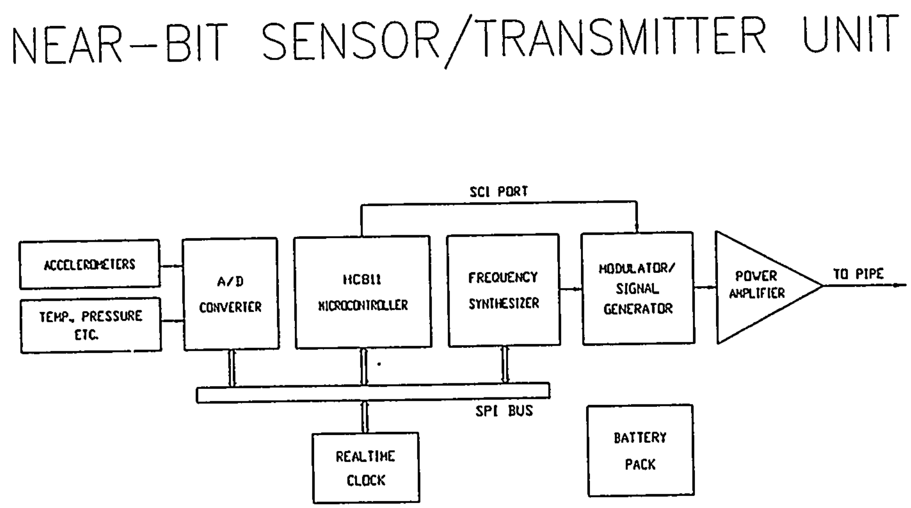

Figure 2. Transmitter Block

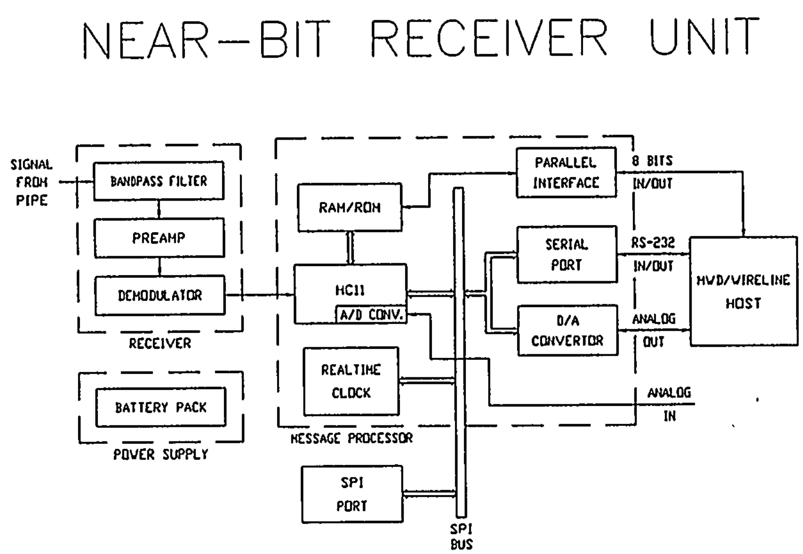

Figure 3. Receiver Block Diagram

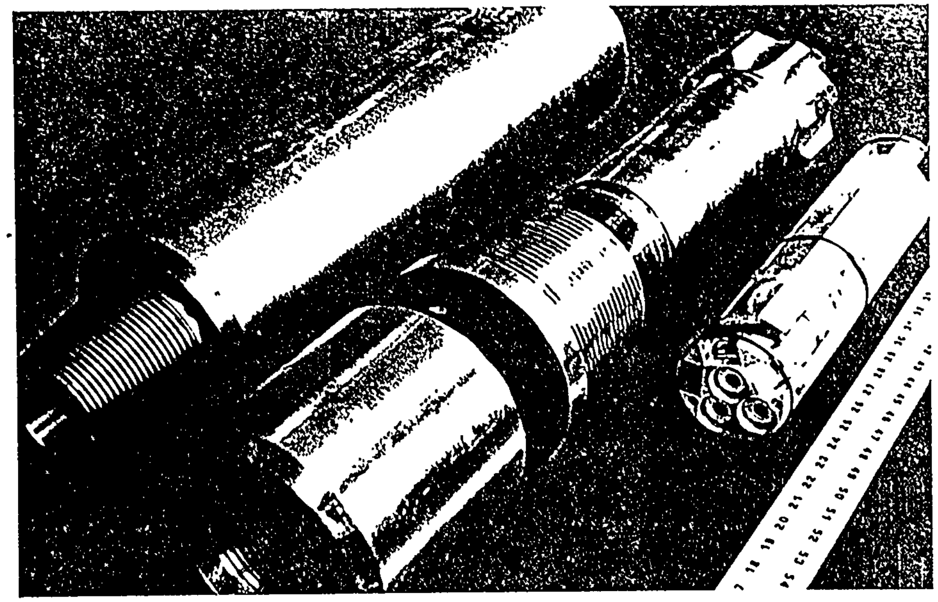

Figure 4. Mechanical Components

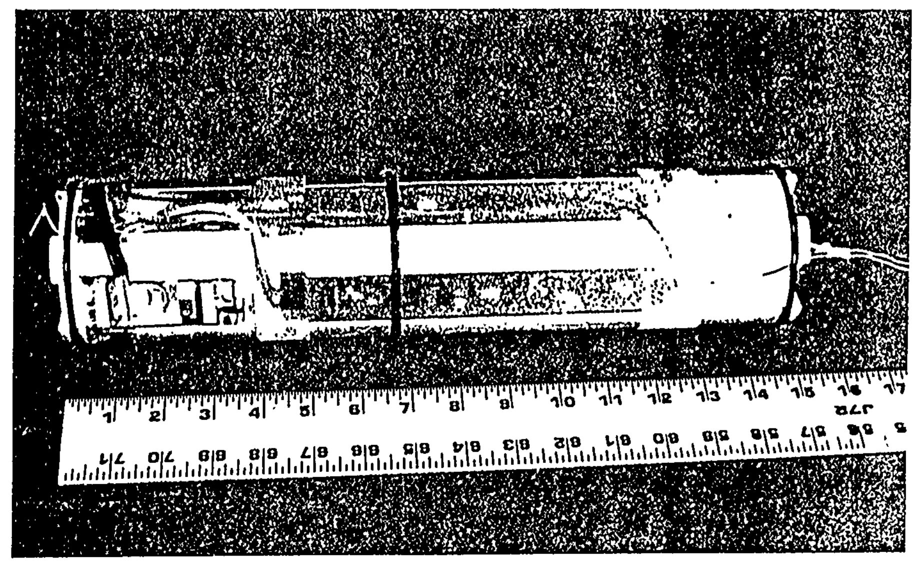

Figure 5. Near-Bit Electronics Mandrel

FUTURE WORK:

The Phase 2 Near-Bit MWD project is currently in the first quarter of work. As such, a significant number of tasks remain to be completed.

The Near-Bit MWD receiver has been configured as a data recorder to enable rapid evaluation of the unit under actual well drilling conditions without the time and costs that would otherwise be required to integrate the Near-Bit MWD communications with a third party MWD or wireline probe. The fabrication of this board is now in progress. Once completed, the recording function will be validated in a test well with the transmitter in a non-drilling environment.

The current sensor suite will be expanded to include at least one type of formation property measurement. The research team is currently evaluating inclusion of either formation resistivity or natural gamma ray. A choice of sensor type must be made and incorporated into the existing design.

More strenuous vibration and shock tests must be conducted prior to field evaluation in order to identify design areas in need of improvement. These tests will pay particular consideration to the transverse loading since loading in this direction is a primary culprit in electronic component failures in downhole tools.

Upon completion of the above activities, the expanded Near-Bit MWD system will be evaluated for performance and reliability in at least two wells. The minimum reliability goal is a 100 hour MTBF.

Final design modifications necessary for commercialization will then be instituted based on the test results and the system offered to the market.

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