NMERDI--2-72-4625

DE86 900579

"SMAC" -- SONIC MAPPING AND CALIPER RESEARCH AND DEVELOPMENT

Final Report

Phase IB

Principal Investigator:

Larry E. Handy

Hot Hole Instruments, Inc.
35 Bonnie View Drive
Los Alamos, New Mexico 87544

MASTER

December 1985

The work from which this material is drawn was conducted with the support of the New Mexico Energy Research and Development Institute. However, the author remains solely responsible for the content of this material.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

gsw

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

BIBLIOGRAPHIC DATA SHEET
for reports sponsored by the
New Mexico Energy Research and Development Institute
Santa Fe, NM 87501

1. NMERDI REPORT NO. 2-72-4625	2. PUBLICATION DATE December 1985	3. NO. OF PAGES 41
4. TITLE AND SUBTITLE "SMAC" -- Sonic Mapping and Caliper Research and Development (Phase IB)		
5. AUTHOR(S) Larry E. Handy		
6. NAME AND ADDRESS OF PERFORMING ORGANIZATION Hot Hole Instruments, Inc. 35 Bonnie View Drive, Los Alamos, NM 87544		
7. ABSTRACT (A 200-word or less factual summary of the most significant information. If report includes a significant bibliography or literature survey, mention here.) NOTE: Do not include the preceding parenthetical material in the final copy. The development of the Sonic Mapping and Caliper (SMAC) Tool has been part of an ongoing effort by Hot Hole Instruments, Inc. of Los Alamos, New Mexico, to provide the geothermal, oil and gas drilling industries with improved and accurate tools for the inspection of the insides of boreholes and interiors of wells. Based on the successful completion of a proof of concept phase, referred to as Phase IA, Hot Hole Instruments, Inc. undertook in Phase IB the design and testing of the SMAC Tool. Work was accomplished during the last half of 1984 and the first half of 1985.		
8. KEY WORDS (6 to 12 entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separate key words by semicolons.) NOTE: Do not include the preceding parenthetical material in the final copy. Cased hole; Collar location; Fracture zone; Caliper; Magnetometer; Inner diameter; Open hole; Geothermal		
9. AVAILABILITY Copies of this report are available from the New Mexico Energy Research and Development Institute Information Center, University of New Mexico, Suite M, 457 Washington S.E., Albuquerque, NM 87108. Tel. (505) 277-3661. Please inquire as to price.		

TABLE OF CONTENTS

	<u>Page</u>
Bibliographic Data Sheet-----	ii
Table of Contents-----	iii
List of Illustrations-----	iv
Executive Summary-----	1
Introduction-----	3
Objectives for Testing of Phase IB of the SMAC-----	9
Design Characteristics of the SMAC-----	11
Descriptions of the Test Wells-----	15
Results of Phase IB Design and Testing-----	18
Cable Tests-----	25
Window Tests-----	26
Productive Cover Design-----	33
Transducer Crystal Selection-----	34
Design of the North Sensing System-----	35
Twenty-Four Point Caliper-----	38
Conclusions-----	39
Acknowledgements-----	41

LIST OF ILLUSTRATIONS

	<u>Page</u>
Figure 1 Caliper Graph-----	8
Figure 2 Sonic Mapping and Caliper Tool-----	14
Figure 3 Strip Chart -- Recorder Output-----	15
Figure 4 Edmonton Wellbore-----	16
Figure 5 Synchronous Motor Used in Tests-----	18
Figure 6 Synchronous Motor Results (Time)-----	20
Figure 7 Synchronous Motor Results (Temperature)-----	21
Figure 8 Motor Characteristics vs Cable Length-----	22
Figure 9 Motor Characteristics vs Cable Length-----	23
Figure 10 High Temperature Transformer-----	24
Figure 11 Sample Window-----	28
Figure 12 Sample Window-----	29
Figure 13 Sample Window-----	30
Figure 14 Sample Window-----	31
Figure 15 Sample Window-----	32
Figure 16 Casing Cross Section-----	36
Figure 17 Printer Output-----	37

EXECUTIVE SUMMARY

The development of a Sonic Mapping and Caliper (SMAC) Tool has been part of an ongoing effort by Hot Hole Instruments, Inc. (HHI) of Los Alamos, New Mexico, to provide the geothermal and oil and gas drilling industries with accurate and improved tools for the inspection of the interiors of wells. Phase IA of the project initiated the development of the SMAC Tool. During this phase, an early prototype was tested to establish the potential of the instrument to provide a useful picture of the conditions inside a well. Initially, this data was displayed in the form of a strip chart, an analogue depicting the condition of the walls of a borehole.

During the last half of 1984 and the first half of 1985, the design and testing of the Phase IB tool was performed in accordance with an agreement between HHI and the New Mexico Energy Research and Development Institute (NMERDI).

The objectives for Phase IB development of the SMAC Tool included improving the capabilities of the instrument in three major areas:

- 1) the range of temperature and pressure at which the tool is capable of operating;
- 2) the ability of the tool to map fractures and dip angles within a well in reference to true north; and
- 3) the creation of a computerized 24-point caliper system to provide a digital data display readout.

In order to increase the range of conditions at which the SMAC Tool is capable of operating, all aspects of the instrument were redesigned and tested extensively. Transducer crystals, motors, oils, transformers,

connectors, window materials and the main body of the tool were all exposed to temperatures as high as 600 degrees F and pressures as high as 20,000 psi in the lab. In addition, the tool was tested in the field under a wide variety of well conditions.

A north-sensing device was created in order to increase the mapping capacity of the tool. The design used a magnetometer that was developed to fit within the size limits of the downhole portion of the SMAC.

Work was also initiated to develop the 24-point caliper system. When complete, the digital display generated by a computer from the data will be capable of determining the diameter of a wellbore within plus or minus 0.05 inches.

While under development, the SMAC was tested extensively in the HHI Laboratory in Los Alamos, New Mexico. Further testing took place under field conditions at the Fenton Hill Geothermal Site operated by the Los Alamos National Laboratory (LANL) in the Jemez Mountains west of Los Alamos. In addition, field tests were performed in a well in the oil fields of Edmonton, Canada.

INTRODUCTION

The earliest wells were dug by hand and operated with a bucket tied to the end of a rope and were among the earliest technological achievements of prehistoric farmers. The history of mankind has involved venturing further underground in search first of water, much later of oil and gas, and most recently the power available from geothermal sources in areas of the world where the earth's heat can be harnessed for energy.

As the complexity of wells has increased, so has the potential for problems. And, as the potential for problems has increased, so has the value of reliable information about the state of the interior of a well.

Until recently, the problems inherent in probing the hostile underground environments of many wells made reliable data concerning the conditions of most gas, oil, and geothermal wells difficult to obtain. HHI began the development of fast and accurate methods of monitoring downhole conditions within a well.

Early HHI tools, the PAT, the PATS and the Spinner, monitored the pressures, temperatures and flow rates within wells. The experience gained in developing such instruments led to the creation of the SMAC Tool, the most advanced of the three generations of instruments developed since the company was founded by Mr. Larry E. Handy.

Many of the concepts which led to the development of the SMAC grew out of Mr. Handy's previous employment as Project Leader in the Geothermal Division of the Los Alamos National Laboratory (LANL). Between 1975 and 1981, the Geothermal Division developed the first generation of well logging tools capable of functioning in a hazardous well environment, where high temperatures and pressures are present, in order to monitor the conditions

within the wells involved in the LANL Hot Dry Rock Program. While with LANL, Mr. Handy was involved in the early design of many of the well logging tools.

The SMAC is a descendant of the LANL instruments. Based on a micro-processor imaging device, the tool will ultimately be able to provide information not unlike that which would be delivered by a tiny television camera. The tool, which is currently awaiting final software changes so that it can go into production, uses sound waves to "see" underground and translates this information into several different forms. One is the analogue strip chart which displays, in light and dark areas, the strength of the signal as it is reflected from the walls of the borehole. The other is a digital readout system. In this system, 24 data points are displayed for each revolution of the downhole portion of the SMAC Tool. This data is sufficiently detailed that a well operator can, for instance, determine if a casing pipe is out of round and, in consequence, vulnerable to collapse.

The drilling industry has responded to the early developments of the SMAC with enthusiasm, for the reliable information provided by the tool has proved most useful in making the decisions vital to the profitable operation of a well field.

Cased wells are commonly found in the oil extraction industry. In cased wells, the borehole is lined with pipe, for either part or all of the distance. As the well ages, this pipe tends to develop a wide range of problems, including rust patches, erosion spots, splits, and cracks. Wells that operate within either an acid or a salt water environment are particularly prone to damage and sections of the casing will ultimately collapse. If this happens without warning, the operator is forced to shut down the well

in order to undertake the lengthy and expensive project of drilling out and replacing the damaged sections.

Information provided by the SMAC Tool allows the well operator to predict the behavior of the casing and replace damaged sections on a planned basis.

In addition, the lower one to two thousand feet (the production zone, that part of the well where the oil is extracted) of a completely cased well are perforated. These perforations, which are designed to allow the free flow of oil, eventually become clogged with mineral deposits and the production of the well is greatly reduced. The picture of the condition of the perforations provided by the SMAC Tool helps the well operator choose the optimum time to inject acid into the well to clear the perforations and increase the production.

There are also boreholes which are not cased. In such wells, information concerning the natural fractures in the rock through which the boreholes are drilled is vital for the field operator. The dip angle, or direction in which such fractures incline, helps provide clues needed to determine the location of the geologic dome that holds the main reservoir of oil and gas in the field, for the fractures rise up into the dome.

The newest model of the SMAC, the tool that has been equipped with the ability to display true north in relation to the dip angles, can provide this information.

In a comment on the value of HHI tools, George Seiber of Scientific Drilling International, said, "Our reservoir engineers are having a feast with the data they are getting. Six months to a year back (before the use of HHI tools), there was no way to get that data."

There is also a sector of the geothermal industry that is well served by instrumentation capable of mapping fractures. In the geothermal hot dry rock process, two wells must be linked by underground fractures that pass through a zone of high-temperature rock. In order to extract energy from the heat within the rock, water is injected into one well to travel through fractures and emerge at the other well at a high enough temperature to be useful as a source of energy.

Two wells that prove not to be linked by rock fractures are useless for the purposes of the hot dry rock process. The ability of the SMAC to map the fractures extended outward from each of a pair of wells helps determine, not only the angle of the fractures, but their relationship with north. This increased information assists a field operator in determining if the two wells are indeed linked.

Based on the successful completion of a proof of concept phase, referred to as Phase IA, HHI undertook Phase IB, the design and testing of the SMAC. This phase of the overall project, begun in the latter half of 1984, was undertaken in conjunction with the New Mexico Energy Research and Development Institute in order to move the SMAC closer to the stage of manufacturing, which will be done in Northern New Mexico.

The project was intended to:

- 1) extend the capabilities of the SMAC so that the tool could operate at vastly greater temperatures and pressures;
- 2) design a magnetometer system in order to give the SMAC the capability of mapping fractures at dip angles with reference to true north; and
- 3) enhance the ability of the tool to provide detailed information concerning the interior of a borehole.

A computer program was also to be developed to enable the tool to provide a computerized digital data display readout from a 24-point caliper system. This is a system which displays one point of data every 15 degrees of the circumference of the inside of the borehole during every revolution of the tool. Digital data from the caliper was to be added to the analogue data, which is displayed in the form of a strip chart.

This report covers the Phase IB development of the SMAC Tool by HHI.

CALIPER GRAPH

Figure 1

This graph represents two points (one at 90° and one at 280°). This caliper data was reproduced many times with the sample casing in the Laboratory. With the repeatability and reliability of the data obtained and the results from the two-point computer graphic output, the decision to expand the caliper to a 24-point was made.

OBJECTIVES FOR TESTING OF PHASE IB OF THE SMAC

The testing of the Sonic Mapping and Caliper Tool (SMAC) during Phase IB of the project was designed to assist in the selection of designs and materials best able to withstand the elevated temperature and pressure found in a hazardous well environment. The design goal for Phase IB was the fabrication of a prototype SMAC that would be able to function at temperatures up to 600 degrees F and at pressures up to 20,000 psi.

The components of the existing SMAC that were to be redesigned to meet these goals included the motors, the oils, the transducer crystals, the window (behind which the crystal rotates), and the main body of the tool. All components of the redesigned SMAC were to be tested, both in the laboratory and in the field. The window was also to be tested in order to select the shape and materials best able to transmit the signal from the transducer to the well interior within a hazardous environment.

The objectives of Phase IB development of the SMAC also included development of a 24-point caliper system. This was to be a computer-generated digital display of 24 data points per revolution of the tool. The caliper was also to have the added ability to display an increase of data--up to 500 data points per revolution over a limited area of the well-bore.

In order to develop the 24-point caliper, a suitable minicomputer and microprocessor had to be selected for use with the enhanced SMAC. The software for the system was written in-house at Hot Hole Instruments, Inc. (HHI).

The ability to map the fractures within the borehole with reference to true north was another planned enhancement of the SMAC. In order to achieve this goal, a commercially available magnetometer was selected

and redesigned so that it would fit inside the space limitations of the downhole portion of the tool.

During the design of the Phase IB prototype SMAC, all aspects of the equipment were tested extensively, both in the laboratory and in the field.

DESIGN CHARACTERISTICS OF THE SMAC

The Sonic Mapping and Caliper Tool is an imaging device that uses high frequency sound waves to provide information on the conditions in the interior of a wellbore. Structurally, the SMAC consists of two sections, an above ground control chassis that both controls the tool and displays data, and the downhole portion of the tool which contains the rotating device that emits the sound waves to probe the well borehole.

In the standard version, the downhole tool is ten feet long and 1-11/16 inches in diameter. The high temperature version of the SMAC is slightly larger, twelve feet long and three inches in diameter. The heart of both versions of the downhole tool is a transducer, a vibrating crystal located near the tip of the rotating shaft within the main body of the tool. Protected by a teflon "window," the transducer crystal vibrates at a frequency of approximately one megahertz (MHz) and produces 500 signals during each revolution of the shaft. These sonic pulses are what are reflected from the wall of the borehole, detected and converted back into electrical pulses by the transducer before being sent through a transformer and pulse conditioning circuitry to the microprocessor portion of the tool located on the surface.

The microprocessor, which runs software designed and written by HHI personnel, amplifies and displays the signals on a strip chart recorder and a digital printer.

The condition of the inner wall of the well borehole affects the reflected signal in such a way that the analogue strip chart, which displays data from the downhole portion of the SMAC in the form of light and dark areas on a strip of paper, provides an accurate, readable picture of the interior of the borehole. Since the smoother areas on the interior surface

of the borehole produce strong reflections, the signal returning to the transducer from such an area produces a dark area on the strip chart. Rough patches on the borehole produce weak reflected signals and light areas on the strip chart. Changing the gain, the strength of the signal produces a more detailed chart, one that can allow the operator to, for example, differentiate between a patch of rust on the casing and an actual hole or pit.

The completed Phase IA version of the SMAC was capable of resolving data from both open and cased boreholes ranging in size between 2 and 24 inches in diameter. The tool is able to detect wall fractures as small as 0.05 inches wide in an 8-inch internal diameter (I.D.) casing and 0.10 inches wide in a 24-inch I.D. casing.

The addition of a 24-point caliper system is one of the greatest changes in the design of the Phase IB tool. This is a system which will display digital data from the downhole portion of the tool in a format of 24 columns, either on a computer monitor or as a hard copy print-out. As in the case of the analogue, the strength of the reflection is a function of the condition of the borehole.

The transducer actually produces 500 data points per revolution, but current computer memory capacities allow for the display of only one data point every 15 degrees around the circumference of the borehole. While this is far less than the maximum data theoretically available, the resulting 24 points per revolution is entirely acceptable within the industry at this time. The capability of the SMAC to display an increased number of data points will be enlarged as the memory capacity of microprocessors, especially those of a size and structure suitable for operation within an oil field, increases.

In spite of computer limitations, it is possible to display small areas within the borehole using the precision of 500 data points per revolution. Within given boundaries, approximately 10 degrees of the borehole, the entire capacity of the tool is available, making it possible to map erosion points to within 0.01 inches.

It is expected that users of the commercial SMAC will find the combination of an analogue strip chart and the digital readout to provide the most complete picture of borehole conditions currently available in the industry. The analogue readout is particularly useful for the display and mapping of angles and fractures within an open hole, especially in conjunction with the magnetometer feature of the tool since this displays true north in relation to the fractures, making it possible to map the fractures.

Among the particular capabilities of the digital display is that of determining if the casing of a borehole is distorted. This information can warn the field operator of a possible upcoming collapse of a section of the casing. The digital readout is also capable of providing an extremely accurate picture of the extent of the erosion and splitting which is endemic in well casings, especially those in sour, or acidic, wells, and those in the salty environment of an underseas well.

Information concerning the erosion and insipient collapse of a well casing can save the operator of a well field considerable money. While it is expensive to replace a casing, it is far more expensive to do so unexpectedly, when it has become necessary to drill one that has failed out of a well for replacement.

Now that the Phase IB development of the Sonic Mapping and Caliper Tool is 95% complete, the SMAC has become a tool capable of operating in and

providing extensive and accurate data from an environment with temperatures up to 600 degrees F and pressures up to 20,000 psi.

Figure 2

SONIC MAPPING AND CALIPER TOOL

DESCRIPTION OF THE TEST WELLS

An oil well in Canada and geothermal wells in New Mexico and California were used in the field testing of the SMAC.

The well in Canada was located in the province of Edmonton. Extensive work on the development of the Phase IA analogue strip chart was done at this well, which is approximately 35 years old and filled with a solution of oil and brine. The well has an I.D. of 7 inches and is cased for the first 3300 feet. An additional 120 feet of the well is open hole, with the fracture zone extending for 50 feet below the end of the casing. Seventy feet of production zone lie below the fracture zone. In this particular well, the production zone is below the end of the casing, eliminating the need for perforations. The temperature encountered in this well is approximately 30 degrees Centigrade or 85 degrees Fahrenheit.

Figure 3

STRIP CHART -- RECORDER OUTPUT

Figure 4
EDMONTON WELLBORE

Figure 4 shows the relationship between the casing and the openhole wellbore in the Edmonton well. The accompanying strip chart (Figure 3) shows the same features as displayed by the SMAC Tool. The following is a brief description of the areas indicated in the figures:

- a. The level to which the concrete backed up as the casing was cemented into place.
- b. The casing collar.
- c. The exact location of the float collar.
- d. The guide shoe and the end of the casing, both cemented to the borehole.
- e. The fracture area, directly below the casing, and extending 40 feet to the production zone.
- f. The production zone, which extends for 60 feet below the fracture zone.

The other two test wells were experimental geothermal wells operated by LANL at the Fenton Hill Site in the Jemez Mountains west of Los Alamos, New Mexico. These wells, part of the LANL Hot Dry Rock Geothermal project, were both filled with hot water.

Well GT-2 has an I.D. of 7 inches and a temperature of 100 degrees C or 212 degrees F at a depth of 2,000 feet.

Well EE-2 has a temperature of 75 degrees C or 165 degrees F at 700 feet below the surface. It has an I.D. of 9-5/8 inches.

The final test well, also a geothermal one, is located in the geyser fields near Santa Rosa, California. It is a steam producing well with temperatures up to 300 degrees C and a flow rate of 300,000 pounds per hour.

RESULTS OF PHASE IB DESIGN AND TESTING

By the end of August, 1985, the development of the SMAC was 95% complete. All the structural components had been selected, designed, and tested at the temperatures and pressures specified by this phase of the development. All that remained to be finished was the final work on the software for the 24-point caliper system. A program had been written to display 2 data points on a digital readout but the software needed the expansion necessary to display 24 points of data.

MOTOR TESTS

Figure 5

SYNCHRONOUS MOTOR USED IN TESTS

Two different motor models were selected for use in the tests to determine motor RPM, torque, reliability and power consumption under high pressures and temperatures. Both were supplied by the same manufacturer but had different torque ratings. The tested motors were also all the same size with different gear ratios.

Motor testing involved running the motors, rated at 180, 240, and 360 RPM, at high temperatures and pressures. In some cases the test motors were run continuously for 10 days at temperatures as high as 600 degrees F.

There was only one dramatic failure during this phase of the testing. One of the motors suffered a temporary failure in which particles from the rotary transformer, one of the essential internal sections of the SMAC, fell into the bearings of the motor during testing. While the incident did cause the motor to stop, cleaning of the bearings restored the motor to a running condition so that the test could be completed.

All of the tested motors performed in a satisfactory manner under the required conditions. In the end, the 180 RPM motor was selected for use in the prototype tool during further testing in the oil fields of Edmonton, Canada.

It was its relatively low speed that led to the choice of the 180 RPM motor for ordinary use in the SMAC; larger diameter holes can be analyzed using a 180 RPM motor because the slower revolving speed of the tool allows time for more of the reflected signal to return from the walls of the bore-hole to be analyzed.

When greater signal resolution is needed during the analysis of holes with smaller than average diameters, it will be possible to use the 360 RPM motor which also performed very well in the laboratory tests.

Figure 6

Each motor retained a constant speed while applying a constant voltage. All motors were tested for at least 10 hours of continuous duty and for 10 separate test runs.

Figure 7

All motors (180, 240, and 360 RPM) fell within the envelope shown in the graph above. As the motors were heated, the speed remained constant but there was a small increase in current.

Figure 8

The three different motors remained at constant speed, regardless of cable length, while constant current was applied.

Figure 9

The input voltage had to be increased from 110 v at zero ft. cable length, to 140 v at 20,000 ft. This increase in voltage took place because of the increase in resistance of the cable as the distance between control chassis and tool increases.

TRANSFORMER

Figure 10

HIGH TEMPERATURE TRANSFORMER

This is the final shape and size of the high temperature transformer used in the SMAC. Of the various transformers tested, this particular model yielded less degrading than the others. This transformer degrades from 20 to 25 percent over the temperature range of 80 degrees F to 600 degrees F. This is a large change in voltage, but the best of all tested.

CABLE TESTS

Since the downhole portion of the SMAC operates in the field at a considerable distance from the above-ground power source, the motors, connectors, and transformers associated with the downhole tool were tested with 20,000 feet of cable separating the motor from the power source. As can be seen in Figure 8, there was no observable degradation in motor, connector, or transformer performance under these conditions.

WINDOW TESTS

The design of the window, the portion of the tool which both transmits the signal from the transducer crystals and admits the reflected signal back into the tool, involved consideration of a large number of possible materials and configurations.

Among the materials chosen for extensive testing were two forms of teflon, PFA and TFE, as well as the mineral quartz. Although teflon is much softer than quartz and tends to become spongy and easily deformed after 8 hours at 600 degrees F, TFE was ultimately selected as the most satisfactory window material since it allows the maximum signal transmission even at high temperatures.

Teflon is moderately soft and can be expected to deform at the high pressures found in hazardous well environments, so the body of the SMAC was designed in such a way as to minimize the pressure differential between the environment in the well and the interior of the downhole tool. An occasional failure in the pressure equalization system demonstrated the effectiveness of the method; without protection, the window imploded, collapsing like a plastic bottle taken too quickly from high to low altitudes.

Further window tests determined the shape and texture of the material needed to optimize the transmission of the signal from the transducer. A number of different possibilities were explored and the one that proved most acceptable was a relatively simple cylindrical design with both the inner and outer surfaces of the window smooth.

This was a design that did produce a small extraneous signal in the output display of the SMAC, the product of a slight reflection from the window. The problem was not a serious one however, for the window signal

was predictable in size and shape and could be electronically locked out of the circuitry without degrading the useful data obtained from the reflections from the walls of the boreholes.

SAMPLE WINDOW

Figure 11

This particular window had grooves cut on the inside in hopes of collimating the signal into one of more gain. But the small increase in gain did not add significantly to the overall performance. Therefore, the smooth interior was chosen.

SAMPLE WINDOW

Figure 12

This specimen does not yield the pressure or shock characteristics as that of Figure 15.

SAMPLE WINDOW

Figure 13

This small shaped window performed the same as Figures 14 and 15. The window in Figure 15 was chosen for the final design because of the shock characteristics.

SAMPLE WINDOW

Figure 14

This sample is identical to the one that is used in the first design except the upper portion was undercut to test for increased signal strength. There was essentially no gain in amplitude with this undercut model.

SAMPLE WINDOW

Figure 15

This is the final design used because of the shock and pressure characteristics. The gain from this window is as good as any tested.

PROTECTIVE COVER DESIGN

One aspect of the SMAC that had not been planned when Phase IB was first considered was a cover for the tip of the downhole tool. After initial tests in the field, it became appropriate to consider the design of an outer cap for the main body of the tool. This refinement was not meant to strengthen the SMAC tool against hazardous well conditions, but to insulate the instrument against careless handling in the field.

TRANSDUCER CRYSTAL SELECTION

The selection of the proper material for use in the transducer was one of the most vital decisions in the design of the Phase IB SMAC. A vibrating crystal, the transducer had to perform nearly flawlessly at the required temperatures and pressures. Any degradation in the vibration of the crystal would result in a loss of accuracy in the data.

Among the possibilities explored were the compounds lead metaniobate, modified lead titanate, sodium bismuth, and lithium niobate. While the last, lithium niobate, did not match the performance of some of the other crystals at moderate temperatures and pressures, it was resistant to degradation as the temperatures and pressures rose, so it was ultimately selected for use in the SMAC designed for use in hazardous environment wells. In more conventional wells, where neither the temperatures are as extreme, the other crystals will prove useful.

DESIGN OF THE NORTH SENSING SYSTEM

As planned, a magnetometer was incorporated into the SMAC for use as a north sensing system. The magnetometer selected was a commercial one, redesigned by personnel at HHI to fit into the one inch diameter confines of the interior of the SMAC. Field tests of the completed unit demonstrated that it was indeed possible not only to map underground fractures, but to provide the map with reference to true north. In cases where a series of fractures provides information of the probable location of a geologic dome containing oil and gas, the reference of true north will be highly valuable to a driller planning the locations of new wells.

CASING CROSS SECTION

Figure 16

DEPTH IN FEET	NORTH	RADIUS IN INCHES						
		0°	45°	90°	135°	180°	225°	270°
200.0	3.50	3.55	3.45	3.50	3.65	3.50	3.50	3.45
200.5	3.50	3.55	3.45	—	—	—	—	—
201.0	3.50	3.55	—	—	—	—	—	—
201.5	3.51	—	—	—	—	—	—	—
202.0	—	—	—	—	—	—	—	—

Figure 17
PRINTER OUTPUT

TWENTY-FOUR POINT CALIPER

Each revolution of the downhole portion of the SMAC has the potential of producing 500 data points. At a speed of 3 revolutions per second, the SMAC is capable of producing 1500 data points per second ($500/\text{rev} \times 3 \text{ rev/sec}$), an unsurmountable amount of data to present in digital format on a printer.

It is possible to store this quantity of data for a short period of time (when the observation area is limited in size) but it is not feasible, given the current memory capacities of available microprocessors, to do this for the entire logging run. Therefore, the method of taking samples every 15 degrees, or 24 points per revolution, was chosen to fall into the capabilities of many printers and tape storage units.

Work on the software to control the 24-point caliper began with the choice of an Intel microprocessor and a DEC minicomputer as the necessary hardware. To begin, a program was written which displays a 2-point caliper, with data taken from the opposite sides of the insides of the borehole. This proved to be a very accurate method of determining the inside dimension of the casing.

By the end of Phase IB, at the end of August, 1985, this program was ready to be expanded into a 24-point caliper that would display data from 24 separate points, every 15 degrees around the circumference of the SMAC's sweep around the inside of a well borehole.

CONCLUSIONS

Close to completion, the SMAC promises added power, efficiency, and productivity to the well logging industry, a field that comprises an appreciable fraction of the multibillion dollar geothermal, oil, and gas drilling industries. The tool's ability to provide rapid and accurate information on the state of the interior of a well borehole is already being welcomed by the industry as an appreciable improvement on state-of-the-art technology.

A large number of companies are already using the existing logging tools that have been developed during the past five years by Hot Hole Instruments, Inc. From Canada to California and across the Pacific in Indonesia and the Phillippines, instruments by HHI are providing vital information to drilling managers for companies including Union Geothermal, Chevron, Geothermax, Aminoil, GEO Operator Corporation, and Magma.

At first HHI leased well logging tools to companies such as Ted Anderson Services, Ltd. of Canada, AMF Scientific Drilling, and Drilling Measurements, Inc. of the United States. These companies are among those that provide inspection services to other companies that are actually engaged in the drilling and operation of oil, gas, and geothermal wells.

In a move that opens new horizons for HHI instrumentation, the company has recently expanded to create a subsidiary, High Tech Logging, Inc. The new subsidiary will provide well logging services directly to the drilling and operating companies around the world. This move was planned in order to give HHI an increased independence of the marketing practices of out-of-state firms.

Earnings from High Tech Logging, including those from the operation of the SMAC, will add to the economy of Northern New Mexico. High Tech

Logging has already signed a contract with Chevron Geothermal for the logging of wells with existing equipment in Southern California.

The completion of the development of high quality technology in Northern New Mexico will benefit far more than the world-wide drilling industry. Once the SMAC is in production, there will be major benefits to Northern New Mexico.

By approximately January 1, 1986, Hot Hole Instruments, Inc. will open a new production facility in the East Gate Industrial Park of Los Alamos, New Mexico. The move to greatly expanded quarters will give HHI the opportunity to increase not only production, but employment in Northern New Mexico.

In fabricating the existing HHI production line, the PAT, PATS, and Spinner tools, and in the future fabrication of the SMAC as well as the electronics that control all HHI downhole tools, the company will draw heavily from the Northern New Mexico labor pool. It is expected that full production of the HHI line of well logging tools, instruments that will be used world-wide by out-of-state firms, will employ many residents of the Northern New Mexico area.

ACKNOWLEDGEMENT

I would like to thank Sue Martin for her assistance in administrating Phase IB, formatting and supervision of the final report; Ted Anderson of Ted Anderson Services, Ltd., Canada; Bert Dennis, his entire ESS-6 Group, and to associated Fenton Hill personnel of the Los Alamos National Laboratory for their cooperation and assistance throughout Phase IB of this project.

The staff of HHI would especially like to thank Larry Icerman, John Lansdowne, and the entire NMERDI staff for their sincere interest and support of this project. Their dedication and cooperation, along with their help in securing business and financial contacts, were crucial to the continued development of HHI.