RESEARCH AND DEVELOPMENT OF A SEISMIC IMAGING SYSTEM

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Abstract

A clamped seismic receiver capable of being clamped into and removed from a borehole is being developed. An Extensive development programme with the emphasis being on producing high quality, large bandwidth (resonance free) data has produced unexpected results and greatly improved the understanding of the dynamic problems associated with such devices.

The developments described are aimed at producing a clamped tool capable of producing 1 KHz bandwidth data in a 175°C, 140 MPa environment.

Introduction

In the early 1980s the Camborne School of Mines, through the UK HDR Geothermal Project, began researching and developing equipment capable of measuring and locating the microseismic events associated with the creation and operation of geothermal reservoirs. Since 1991 this activity has been carried out by CSM Associates Ltd (CSMA).

Commercial Tool Evaluation

A commercially supplied instrument was selected and subjected to a thorough field and laboratory test programme.

The tests were performed in CSMA's shallow (300 m) borehole system which consists of four boreholes located on a 10 m square grid.

The instrument was clamped in one borehole and detonators fired in the other 3 boreholes.

Measured from the vertical, a dip ranging from 60° to 150° was measured by the instrument as 81° to 100".

The azimuth differences were generally determined by the instrument to within 10" of the actual value, occasionally within 5".

The laboratory tests determined the transfer or frequency response function of the instrument.

The unrestrained (free-free) response was measured with the instrument supported on soft pads and the clamped response by placing it in a concrete trench used as a borehole simulator.

The laboratory investigations were supported by computer modelling (finite element analysis) techniques. The combination of these two analysis methods enabled a good basic understanding of the issues controlling the performance of clamped instruments to be developed. Namely the structural resonances and the difficulties in suppressing resonances by restraining clamps.

The response functions of the instrument free-free and clamped are shown in Figures 1 and 2. The mode shapes associated with the frequencies were estimated from the finite element, (FE) models and the first three modes are shown in Figures 3 and 4 for free-free and clamped conditions respectively. The FE models were used to evaluate the potential benefit of adding additional clamps to restrain low frequency mode shapes, but the frequency only increased to 188 Hz.

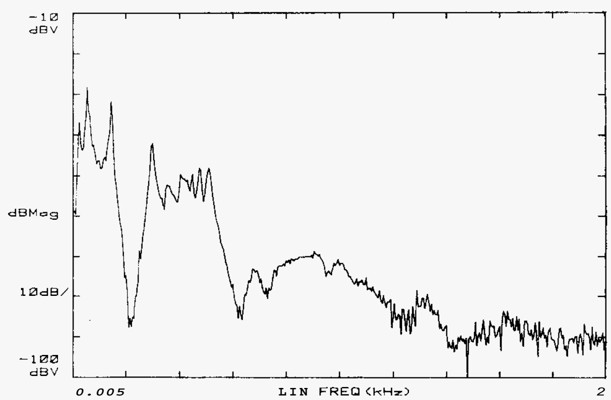

Figure 1 Frequency Response Function [FRF] Free-Free

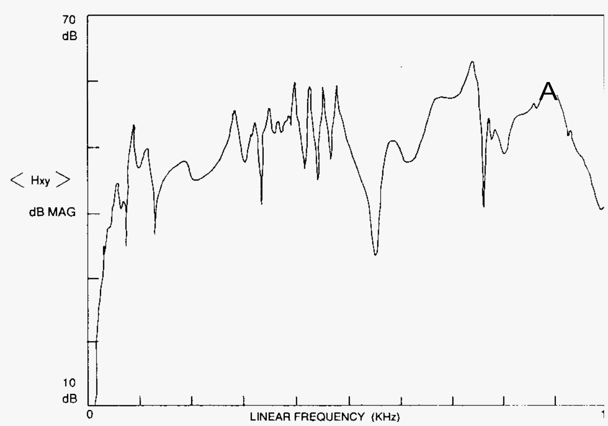

Figure 2 Normalised FRF Clamped in Test Trench

Several comments can be made from these investigations.

1 The vertical compression of the measured locations of seismic events is typical of instruments whose physical geometry ensures low frequency bending (horizontal) resonances combined with relatively high frequency axial (vertical) resonances.

2 Attempting to simulate downhole clamped conditions in a simulated borehole is fraught with difficulties and serves as a poor substitute of the actual situation.

3 FE modelling represents a potent tool for analysing and predicting the frequency response of a structure.

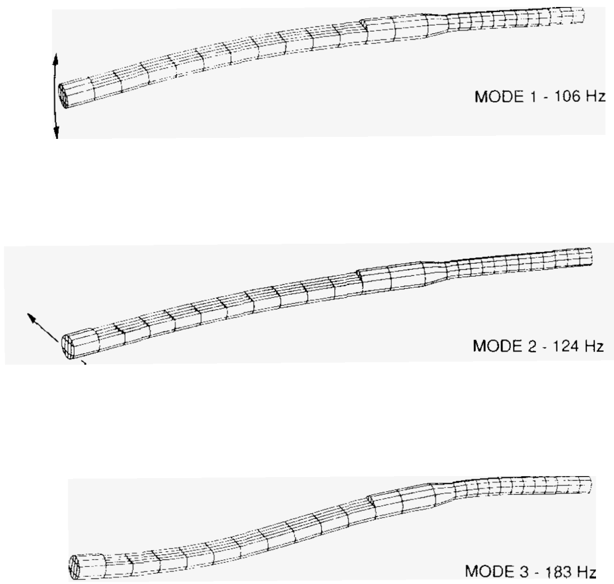

Figure 3 FE Model - Free-Free Mode Shapes

Figure 4 FE Model Mode Shapes Standard Restraints

Custom Tool Development

Having concluded that a commercial instrument would not meet the requirements of the Geothermal Project, a custom designed instrument development programme was commenced.

The principal requirements of the design were perceived to be the need for a high frequency fundamental resonance and a stiffer hydraulic clamp arrangement.

Several design scenarios were considered culminating in the "mother and satellite" arrangement shown in Figure 5. In this arrangement the satellite contains all the sensors and orientation devices along with a slave hydraulic piston assembly to provide the clamp. The mother unit contains all the system electronics and the master hydraulic system to power the satellite. The two sections are separated by a flexible umbilical cable providing the electronic, mechanical and hydraulic connections.

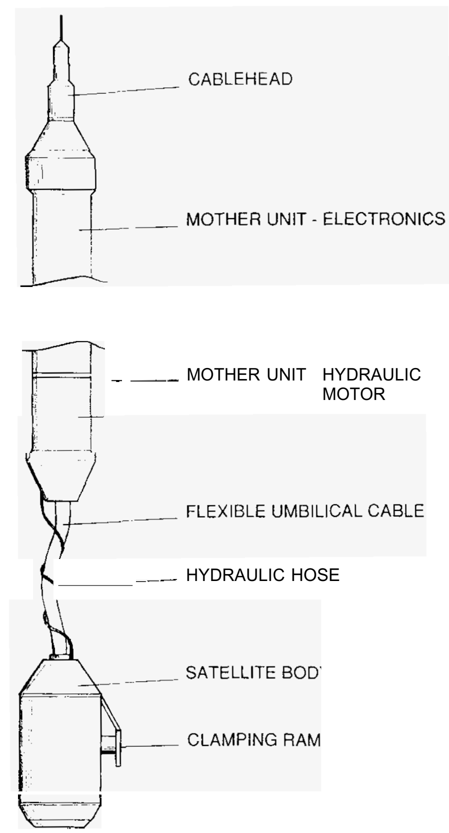

Figure 5 3 Axis System Layout

The satellite was designed and built to be as stiff a structure as the borehole size and the on board system requirements would allow. FE analysis of the design predicted a fundamental resonant frequency of 2395 Hz which compared well with a laboratory measured frequency of 2417 Hz.

Due to practical difficulties (tool size) trench testing could not be considered.

The field trials were a repeat of the previous ones, to evaluate dip and azimuth measurement capabilities.

The frequency spectra for 9 events from one of the horizontal accelerometers in the satellite are shown in Figure 6 for a frequency range of 0-1 KHz. From this a series of large amplitude, low frequency resonances in the range 200-550 Hz can be seen. Despite the fact that each event is at a different depth relative to the satellite, each signal consistently shows peaks at the same frequency. Similar characteristics were evident in the other axes.

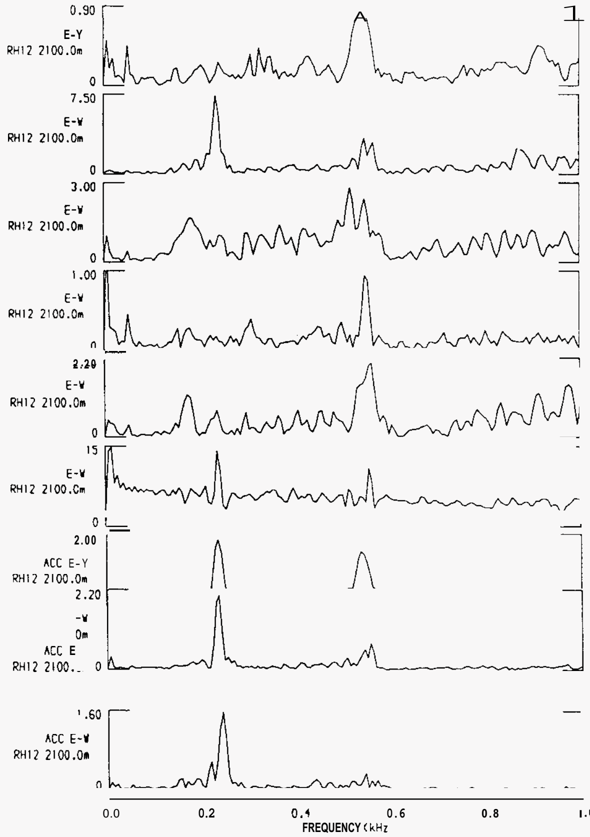

Figure 6 Frequency Spectrum for 9 Events on East-West Accelerometer

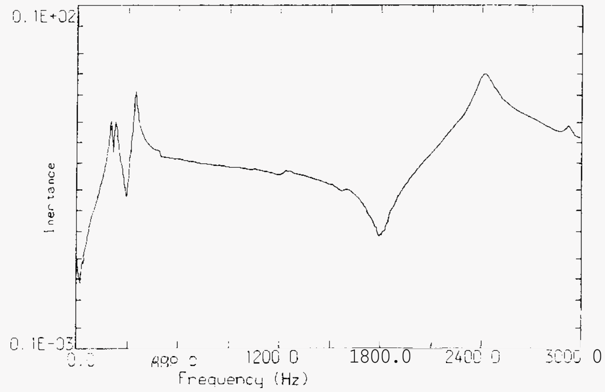

Figure 7 Modal FRF of Satellite Clamped in Granite Block

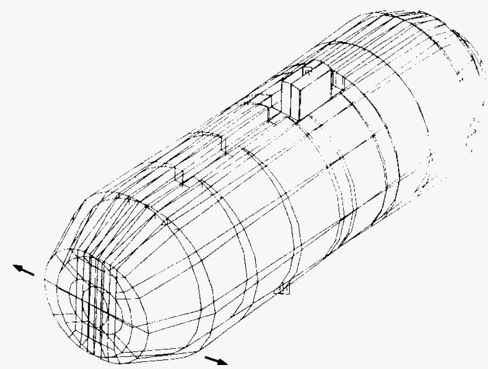

Figure 8 FE Model, Rigid Body [R8] Mode 1 - 223 Hz

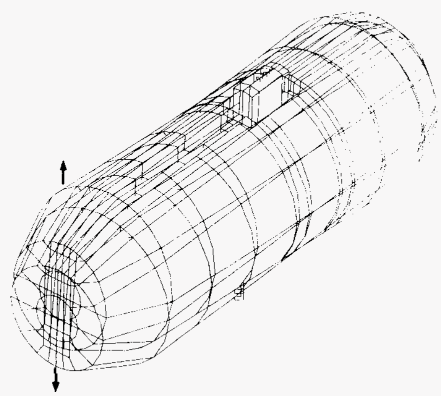

Figure 9 FE Model, RB Mode 2 - 249 Hz

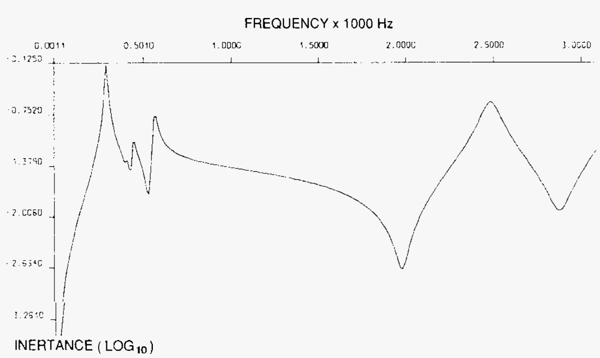

Figure 10 FRF from FE Model of Satellite

The low frequency resonances experienced by the satellite were such that the contamination to the data was too great to enable any location attempts to be made.

This unexpected result led to an extensive series of laboratory tests, using a specially prepared large granite block, with a 216 mm hole drilled in it, to allow improved simulations of the downhole clamped condition.

Evaluation of the in situ (clamped) response function, confirmed the presence of low frequency resonances. Modal analysis techniques were used to determine the nature of the resonances and showed them to be the result of the satellite moving as a stiff, rigid body within the borehole. The contact points between the tool body and granite borehole wall were sufficiently flexible to allow the satellite to vibrate within the borehole as though it were a mass supported on four sets of springs. Each spring set being equivalent to one of the four contact points on the satellite body, permitting "rigid body" motion in three dimension.

The detected motion was a combination of pitching, rolling and yawing. The frequency response function is shown in Figure 7.

Attempts to model the behaviour by FE methods were very successful.

The first two modes of motion for the FE model are shown in Figures 8 and 9. The corresponding frequency response function, Figure 10, shows a good correlation with that obtained from the laboratory (Figure 7).

Given the revealed nature of the rigid body motion and the fact that little could be done with the present design to overcome it, the direction of the tool development was changed. The present satellite system was abandoned in favour of a revised approach.

The design, Figure 11 removed all the orientation system from the satellite and left just the accelerometers and the minimum of conditioning electronics. Orientation would be achieved by maintaining a fixed relative position between the mother section and the (mini) satellite and positioning all the orientation equipment in the mother section. The clamping procedure would be as follows:

(a) Lower tool into the required position.

(b) Clamp the mother section.

(c) Clamp the mini satellite.

(d) Read the orientation of the system.

(e) Retract the restraint between mother and mini satellite to leave the mini satellite dynamically separate from the mother section.

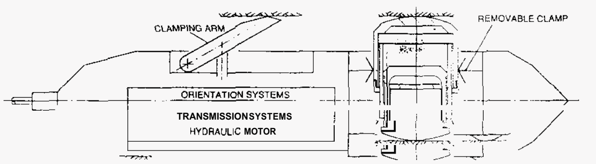

Figure 11 Proposed "Mother" Carrier for Mini Satellite

To further improve the clamping stiffness, the hydraulic ram would be very much larger in cross-section area, thus increasing its stiffness.

Dimensionally the mini-satellite is a maximum of 100 mm in diameter, 116 mm in length, when fully retracted, and can extend to a maximum length of 245 mm. As shown in Figure 11, the mini-satellite extends across the borehole, the ends of the body contacting the wall. The connections between the mother section and the mini satellite would be through spirally wound tubes (to form flexible couplings) which would not cause resonance problems or transmit resonances from the mother to the mini satellite.

Prior to constructing any test models, the design was analysed for any resonances both at a component level and full assembly with encouraging results.

A laboratory model was constructed and evaluated in the test block "borehole".

The results showed a flat response upto 1000 Hz in the satellite's extending axis, but a poor response in a perpendicular plane across the borehole axis.

In an effort to generate a significant increase in contact area and stiffness, the mini satellite was lightly clamped onto bags of epoxy resin located on its end faces. When the epoxy was cured the satellite was firmly clamped in place.

The resulting response functions in the satellite's axial (Figure 12) and cross axial directions, show substantial improvements with the onset of resonances above 1500 Hz and 1300 Hz respectively. The resonance below 100 Hz is due to the test rig arrangement and the presence of 50 Hz electric interference.

An engineered version of the epoxy pads using plastic pads produced similar results with slightly lower frequency resonances.

A development tool for shallow low temperature downhole use, has been constructed and encouraging results obtained.

Electronic developments

Active seismic surveys such as VSPs and crosshole use multireceiver strings with special multiconductor cables or low data rates on standard cables. At DeutscheMontanTechnologie (DMT) a seismic acquisition system has been developed which overcomes these disadvantages.

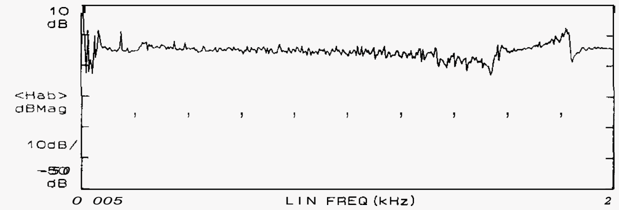

Figure 12 FRF of Mini Satellite Clamped on Epoxy Pads

The principal of this patented system is the digitization of the analogue data at the receivers and the storage of the digital data in the receiver modules own memory. All receiver modules (channels) are connected by two conductors. On command from the central data acquisition and controlling station each channel down loads its memory to the central station. In this way the stacking of seismic records in the receiver modules is also possible as time uncritical data transactions sent to the central station after registration of the source signal. The data recording starts with a trigger impulse that is sent simultaneously on the conductors to all the receiver modules at the same time as the source is activated.

Figure 13 shows the principal design of the developed digital borehole seismic system. At the surface a PC surface unit controls the communications to the subsurface receiver modules in the borehole. It is also used as the data acquisition system and allows in field quality control of the seismic survey directly after each seismic shot. The magnetic orientation of each receiver module and its temperature and inclination can be transmitted in addition to the digitized seismic data to the surface unit.

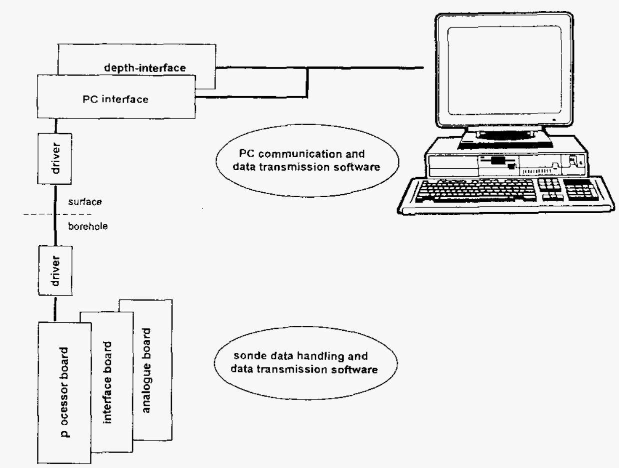

Figure 13 3 Component Tool Electronics System

The cooperative development programme between DMT and CSM Associates Ltd will only utilise a single 3 component receiver system but an almost unlimited number of systems could be added. The present development is aimed at producing a demonstration instrument for use at temperatures up to 100°C and pressures of 20 MPa in 100 mm (4") diameter boreholes. A specification of 175°C and 140 MPa with a usable 1 KHz bandwidth is the ultimate goal.