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IMPLEMENTATION OF RAMPED PRESSURE TECHNIQUE TO MEASURE ACOUSTIC SENSITIVITY OF FIBRE OPTIC HYDROPHONE TRANSDUCERS

ERIC C. MAGI

MRL-TN-656

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Implementation of Ramped Pressure Technique to Measure Acoustic Sensitivity of Fibre Optic Hydrophone Transducers

Eric C. Mägi

MRL Technical Note
MRL-TN-656

Abstract

The theoretical and practical implementation of a measurement technique to obtain both the low frequency acoustic and thermal sensitivities of a fibre optic hydrophone is discussed. An analysis program based on the theory was implemented in Microsoft Excel to obtain the pressure sensitivity of a fibre optic interferometric hydrophone transducer. This method is based on ramping pressures at different rates. A major advantage of the technique is the temperature and pressure effects are clearly delineated and the test system need not be in thermal equilibrium.

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Implementation of Ramped Pressure Technique to Measure Acoustic Sensitivity of Fibre Optic Hydrophone Transducers

1. Introduction

A fibre optic interferometric sensor splits light into two optical paths and then recombines the beams. If one of the paths is subjected to an external influence which changes its optical path length, then the phase relation between the recombining beams is altered. This results in a modulation of the light intensity at the sensor's outputs.

The variation of the optical intensity detected at the outputs of a two arm fibre optic interferometer may be written as^{1,2,3}

$$I(t) = I_0 (1 + V \cos[\phi_0(t) + \theta(t)]) \quad (1)$$

and

$$I(t) = I_0 (1 - V \cos[\phi_0(t) + \theta(t)]) \quad (2)$$

where I_0 is a constant that is proportional to the sum of the power in the individual arms of the interferometer and V is a visibility constant. $\phi_0(t)$ represents random phase changes arising from environmental variations whilst $\theta(t)$ represents the phase change induced by the measurand of interest.

A fibre optic hydrophone is constructed by making an optical path length sensitive to changes in pressure. For low frequencies (<10kHz) this can be achieved by embedding coils of fibre in a compliant material^{4,5}. The compliant material acts as an amplifier imparting strain onto the fibre.

Ideally a sensor should be sensitive only to the measurand of interest, however in practice this is rarely achieved. Fibre sensors tend to be sensitive to both temperature and vibration since both the index of refraction n , and the length L , of the fibre are affected by these parameters.

The acoustic sensitivity, R_a , of an interferometric transducer can be defined as the differential phase shift, $\Delta\phi_d$, per unit change in pressure, ΔP (ie. $R_a = \Delta\phi_d / \Delta P$ in units of rad/Pa, or rad/ μ Pa, etc). In principle we can determine R_a by ramping the static pressure up and counting the resulting fringes⁶. Acceleration effects are

usually not significant using this measurement technique, however thermal fluctuations tend to increase the uncertainty in the value of R_a . Other methods for measuring the pressure sensitivities of fibre optic hydrophones include fixed phase shift technique⁷, Bessel function zero-crossing technique^{7,8} and comparison technique⁹ using acoustic calibrators. Three advantages of a ramped pressure technique are: 1) the method does not require an acoustic source, 2) the simplicity of the experimental apparatus and 3) a demodulation test set is not required for determining the pressure sensitivity of the interferometric transducer.

Magi¹⁰, has developed a modified ramped pressure technique for measuring both the thermal and acoustic sensitivity of interferometric hydrophone transducers. The method is based on ramping pressures at different rates and measuring the fringe frequency as a function of rates of change in pressure. The advantage of this method is that the pressure and thermal effects are clearly delineated which has the advantage that the pressure sensitivity can be measured to a high degree of accuracy. Vibration and acoustic borne noise tends to modulate the fringe frequency. These effects can be clearly identified and accounted for.

This paper outlines the theory on which the technique is based, then describes the implementation of the method to obtain the pressure sensitivity of interferometric fibre optic hydrophone transducers. The main emphasis of the paper is to document the analysis software developed using Microsoft Excel.

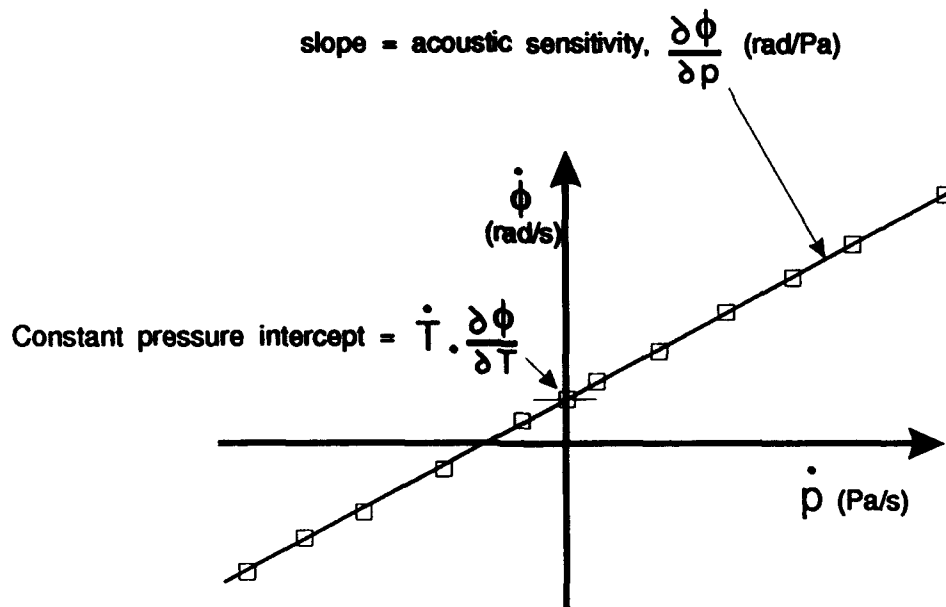


Figure 1: Fringe frequency as a function of rate of change in pressure.

2. Theory

The total phase ϕ , along a length L , of fibre is given by the relation^{4,10}

$$\phi = n.k.L \quad (3)$$

where n is the index of refraction and k is the wave number of the light.

The phase change over a length of fibre is a function of both pressure p , and temperature T , since these parameters affect n and L . Neglecting acceleration, we can write the change in phase, $d\phi$ as

$$d\phi = \left(\frac{\partial\phi}{\partial p}\right).dp + \left(\frac{\partial\phi}{\partial T}\right).dT \quad (4)$$

Differentiating with respect to time we obtain

$$\dot{\phi} = \left(\frac{\partial\phi}{\partial p}\right).\dot{p} + \left(\frac{\partial\phi}{\partial T}\right).\dot{T} \quad (5)$$

The pressure or acoustic sensitivity $\left(\frac{\partial\phi}{\partial p}\right)$ can be obtained by measuring the fringe frequency as a function of rate of change in pressure. The slope of the resulting graph is $\left(\frac{\partial\phi}{\partial p}\right)$, and the value of $\left(\frac{\partial\phi}{\partial T}\right).\dot{T}$ is equal to the constant pressure intercept

(see Figure 1). $\left(\frac{\partial\phi}{\partial T}\right).\dot{T}$ tends to be constant over the duration of each experiment due to the large heat capacity of the water and pressure vessel.

This method of determining the acoustic sensitivity tends to be less sensitive to random variations in temperature and vibration since the slope of the graph is determined using a least squares fit of many data points.

Vibration and acoustic borne noise tend to modulate the fringe frequency. When the noise is a discrete tone, these effects are clearly identified and can be accounted for by estimating the average fringe frequency over a time interval which corresponds to an integral number of periods of the noise signal.

Furthermore the water temperature in the vessel is not required to be in thermal equilibrium.

The rate of heat transfer to or from the pressure vessel is proportional to the difference, ΔT , between room and water temperatures. \dot{T} can be estimated with a high degree of accuracy from measurements of ΔT . The relationship is obtained from the thermal decay curve of the system. By deliberately creating a temperature difference, the temperature sensitivity $\left(\frac{\partial\phi}{\partial T}\right)$, can then be determined¹⁰ from the measurements of $\left(\frac{\partial\phi}{\partial T}\right).\dot{T}$ and ΔT .

3. Experimental Apparatus

A schematic of the experimental apparatus is shown in figure 2. The vessel is instrumented with a pressure transducer, temperature sensor, electrical feed-through and an optical fibre feed-through.

The vessel is filled with water and high pressure nitrogen is supplied to the vessel via a stop-cock and regulator. A venting valve is used to release the pressure.

Low frequency ($\nu \rightarrow 0$) sensitivity tests are performed on the transducers by varying the pressure up and down manually at different rates. The outputs from the fibre optic hydrophone, pressure transducer, and temperature sensors are logged.

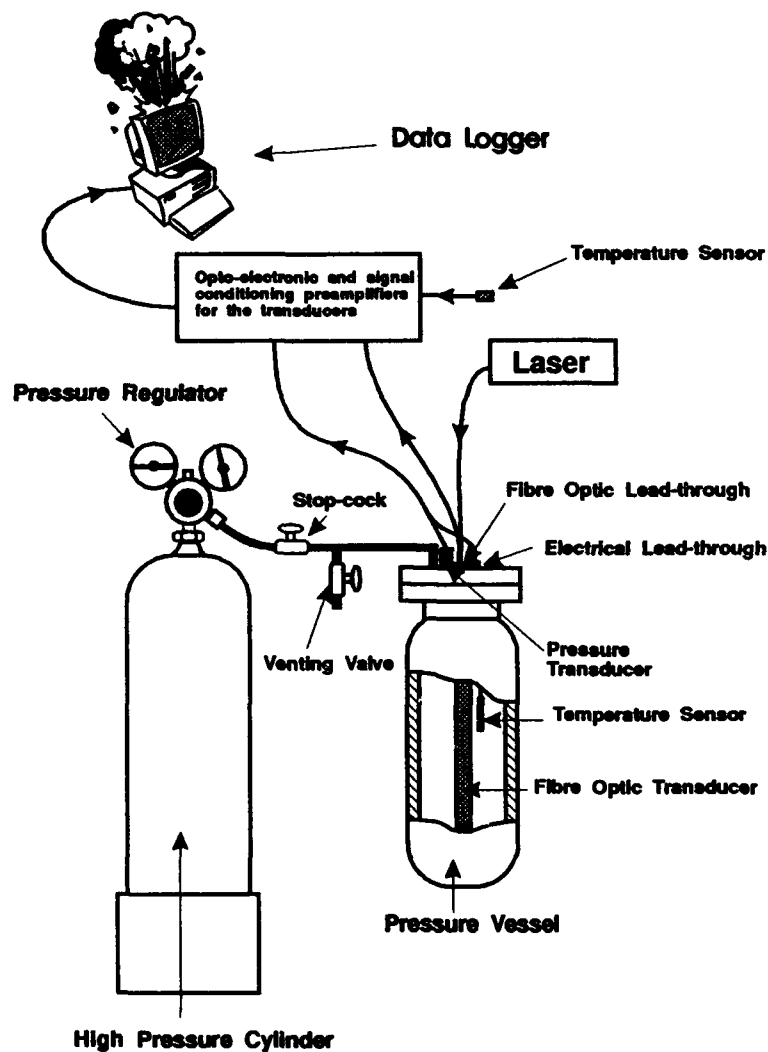


Figure 2: Schematic of Experimental Apparatus to determine the acoustic sensitivity using static pressure method

4. *Implementation*

The data logger used by the author is an AT compatible PC using an Analog devices RTI 860 acquisition card. This acquisition card is capable of synchronous sampling of data in blocks of four channels. It has been decided that four channels of data should be logged at any one time. A software user interface has been developed in-house. This includes triggering features and an optional FFT routine if required. The raw data is saved to floppy disk in ASCII format upon request which can then be transferred to a faster machine for processing.

It was decided that the fringe frequency could be determined by time domain analysis to a higher degree of accuracy compared with estimation using a FFT. The data analysis has been implemented on a spreadsheet(Microsoft Excel) and is semi-automated by the use of macros.

Graphs of the raw data and processed results are displayed on the spreadsheet for use in checks on the integrity of data and results of data processing. The use of a spreadsheet gives a degree of flexibility to intervene in the processing if data are corrupted. It has been found however, that the processing scheme is robust and reliable.

A description of the applications and files used to process the data can be found in appendix A

5. *Description of Block Diagram of Hydanal.xls Worksheet*

A block diagram of the worksheet Hydanal.xls is shown in figure 3. The diagram is a representation of the layout of the spreadsheet and the direction of flow of the data processing. The thick black arrows indicate those sections which are automatically calculated and also included in red are the macro related actions.

It should be noted that the raw data occupies the top left-hand corner of the worksheet and the graphs of the photodetector output are overlaid on the raw data. Sensor calibration data and scaling constants are located in a column which lies between the raw and filtered data.

5.1 *Description of Elements Shown in Block Diagram.*

The default number of data samples which Hydanal.xls is set-up to process is 600 per channel. Descriptions of each element shown in figure 3, are as follows.

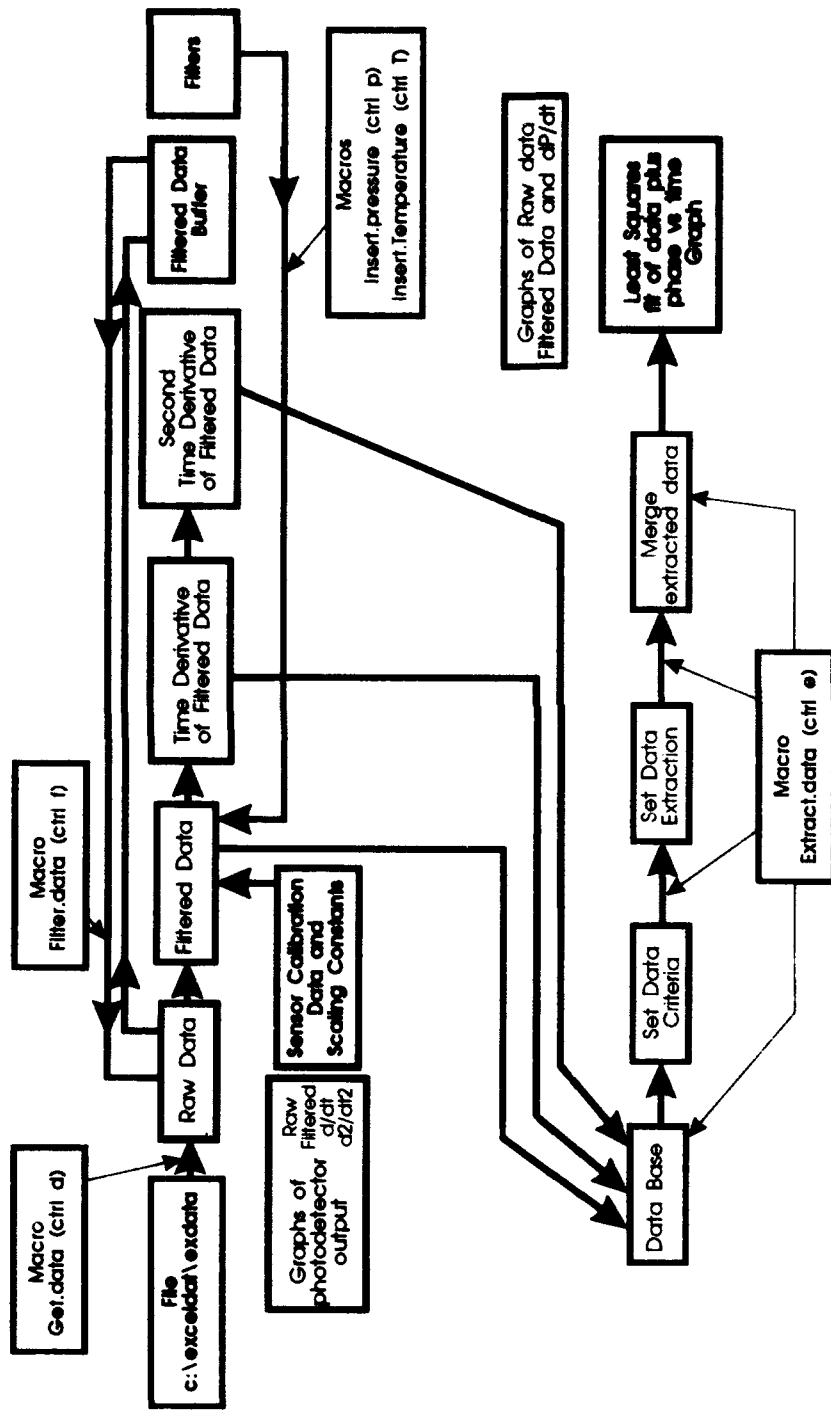


Figure 3: Block diagram of Hydanal.xls Worksheet.

5.1.1 Raw Data

Raw data in integer format are located in six columns(A to F), one column per channel (A-D) and two columns (E and F) for the real and imaginary parts of a 512 point FFT. Also located in the second column (B) is the sampling interval and number of sets of data points.

5.1.2 Sensor Calibration and Scaling Constants

Sensor calibration and scaling constants are located in column F.

5.1.3 Filtered Data

Filtered data contains information on the sample number(column H), sample time(column I), and filtered data from channel 1 to 4(columns J , K, L and M). The filter employed is a five point sliding average filter and the averages are multiplied with the appropriate scaling constants and offsets. The expanded forms of the filters can be found in Appendix B.

5.1.4 Filtered Data Buffer

Four columns(AB to AE) store the results of a five point sliding average filter of the raw data in integer format. It should be noted that the offsets and scaling constants as described in Appendix B, are omitted from the calculations. This buffer is required for use with macro Filter.data.

5.1.5 Filters

Two filters are located in columns Y and Z. Column Y contains a filter for the room air temperature sensor and column Z contains a filter for data obtained from the pressure sensor using the low gain (x200) preamplifier. These filters are for use with the macros Insert.pressure and Insert.temperature. The filters are a five point average filter containing the scaling constants and offsets for the appropriate data as described in Appendix B.

5.1.6 Time Derivative of Filtered Data

Time derivatives of the filtered data are located in columns O to R. It is well known that time derivatives obtained using standard difference formulae are sensitive to noisy data. To minimize this, the time derivatives of the data are estimated from derivatives of least squares fitted, second order polynomials. The polynomial fits are estimated from the four adjacent filtered data points at each sample point.

Since data is sampled at regular intervals, the least squares fit can be estimated by the method of orthogonal polynomials and the estimate of the derivatives are obtained using a modified difference formula(see Ref. 11 page 130-136, equation 17). The difference formula is

$$y'_i = \frac{-2y_{i-2} - y_{i-1} + y_{i+1} + 2y_{i+2}}{10\Delta t} \quad \text{where } \Delta t \text{ is the sample interval.}$$

5.1.7 Second Time Derivative of Filtered Data

The second time derivatives of the data are obtained by applying the same modified difference formula,

$$y'_i = \frac{-2y_{i-2} - y_{i-1} + y_{i+1} + 2y_{i+2}}{10\Delta t},$$

on the calculated set of time derivatives of the filtered data.

The results are located in columns T, U, V and W.

The elements of Hydanal.xls described above occupy rows 1 to 603 of the worksheet. As indicated by the block diagram, the data base, set data criteria, set data extraction, merge extracted data areas and graphs of raw data, filtered data, dp/dt and phase versus time are located below row 610.

5.1.8 Data Base

The frequency of the photodiode signal is determined by use of a database. The idea is to estimate the phase of the signal as a function of time. This is done by constructing a table of estimated times of zero crossings for the first and second derivatives of the photodiode output. A phase is then assigned to these zero-crossing times, and frequency is determined from a least squares fit of the phase as a function of time.

The second derivative of the photodiode output is used in preference to the output since the DC offsets are automatically removed in the differentiation process.

Graphs of the raw data, filtered data, first and second derivatives of the photodetector output are displayed over the raw data columns. These are included for visual checks on the integrity of the data to be used in estimating the frequency.

The database has the following columns of data; Sample Number, Sample Time, Estimated time of zero crossing for the first derivative, Estimated time of zero crossing for the second derivative, Flag1(neg.) and Flag2(neg.). These are in columns H to M inclusive.

Sample Number and Sample Time are obtained directly from the filtered data block. Estimated time of zero crossings for the first and second derivatives are found by fitting a straight line to adjacent points and calculating the time axis intercept, t_0 , using the formulae,

$$t_0(y_0=0) = \frac{\text{offset}}{\left(\frac{\Delta y}{\Delta t}\right)}$$

$$\text{where } y_i = \frac{\Delta y}{\Delta t} t_i - \text{offset}, \Delta y = (y_{i+1} - y_i) \text{ and } \Delta t = (t_{i+1} - t_i).$$

Flag1(neg) and Flag2(neg) are flags which are associated with the estimated times of zero crossing for the first and second derivatives, respectively. A negative value indicates a zero crossing has occurred in the time interval between t_i and t_{i+1} . The formula for the flags is

$$\text{Flag} = (t_{i+1} - t_0) * (t_i - t_0)$$

5.1.9 Set Data Criteria

To obtain the zero crossings from the database, Microsoft Excel requires that an area on the worksheet should define the criteria by which a record is selected.

The columns required for the Set Data Extraction are those of the Data Base. The area defined are in columns O to T. The selection criteria, ≤ 0 , must alternately be placed in the Flag1(neg) and Flag2(neg) columns(S and T respectively). Note that the selection criteria, ≤ 0 , must not be in both Flag1 and Flag2 columns simultaneously since dI/dt and d^2I/dt^2 are never zero at the same time when I (signal from photodetector) is oscillatory.

5.1.10 Set Data Extraction

An area on the worksheet is required for copying data from the database which satisfies the selection criteria as defined by Set Data Criteria. This area is located in columns U to X. The parameters copied in the extraction process are, Sample Number, and Estimated times of zero crossing for the first derivative and Estimated times of zero crossing for the second derivative.

5.1.11 Merge Extracted Data

The time estimates for the first and second derivatives are copied from the data extraction area and are copied into column AD (titled TIME) for sorting into chronological order(by macro extract.data).

Columns AC and AE(titled PHASE) have the values of multiples of $\pi/2$ in ascending order(ie. $\pi/2, \pi, 3\pi/2...$).

In Column AF, three estimates of the slope of the graph, Phase versus Time are made using the function LINEST(Y,X) on different numbers of data points. This is done to obtain an estimate of the uncertainties.

Graphs of Phase versus Time are plotted next to Merge Extracted Data area for a visual check on the time estimates.

An average value for dp/dt is obtained from Time Derivative of Filtered Data and is displayed in cell AF619. The first and last ten data points are omitted from the calculation of the average since end points will tend to a similar value when recursive filtering is applied. If the end points were included, this would have the effect of biasing the result of dp/dt towards zero.

An estimate of the sensitivity is made using the estimates of the angular frequency as determined using the first twenty three time estimates of zero crossings and the average of dp/dt . This estimate is located in cell AF 622 and it neglects the biases introduced by temperature fluctuations. The result is only intended to give an approximate estimate of the transducer sensitivity.

5.2 Description of Getdata.xlm

The macro sheet Get.data.xlm contains five macros and is used in conjunction with Hydanal.xls. The macros are Get.data (ctrl d), Extract.data (ctrl e), Filter.data (ctrl f), Insert.Pressure (ctrl p) and Insert.Temperature (ctrl T). The contents of the brackets (eg. (ctrl d) etc.) indicate the key strokes required to

activate the macro. The code for the macros are given in Appendix C and descriptions of their action are as follows.

5.2.1 *Get.Data(d)*

Get.Data selects the directory C:\exceldat and opens the data file EXDATA. The columns of Data are selected and copied into the clipboard. *Get.Data* then switches to the worksheet Hydanal.xls, selects the home position and then pastes the data into the worksheet. The columns of data are then selected and the columns are formatted to best fit. The unused cell, R1C5 is selected before exiting the macro so as to avoid accidental deletion of the data.

5.2.2 *Extract.Phase (e)*

Extract.Phase (e) first action is to select the area containing time estimates of zero crossings for the 1st and 2nd derivatives, sample number, sample times, flag1 and flag2, then define it as a data base. The next action is to select and set the data extract criteria area, then set the selection criteria for Flag1 and delete condition of the second flag. Time estimates for zero crossing of the first derivative data are extracted from the data base and the condition of the first flag is cleared.

The selection criteria for the second flag (Flag2) is set, then the extraction area for the second derivative data is defined. Time estimates for zero crossing of the second derivative data are then extracted from the data base.

The Time Column in the Merge Data area is cleared. The extracted time estimates for zero crossing of both first and second derivatives are copied and then pasted into Time column of Merge data area. The time column is then selected and the time estimates are sorted into chronological order.

The unused cell R624C34 is then selected before exiting the macro to display the Phase versus time graph, least squares fit values for angular frequency, frequency, estimate of the sensitivity(not accounting for temperature effects), average value for dp/dt and graphs of pressure and dp/dt as functions of time.

The phase versus time graph, least squares fit values for frequency, angular frequency and estimated sensitivity are automatically updated.

Invoking *Get.data* and *Extract.data* is all that is required to process a packet of data to obtain a pair of points $\left(\frac{dp}{dt}, \frac{d\phi}{dt}\right)$ for graphing. This process takes approximately 25 seconds to compute using a PC with a 486 processor running at 33MHz.

If there is excessive noise on the data, the averaging window can be applied to the Filtered Data by invoking the macro *Filter.data*.

5.2.3 *Filter.data (f)*

Filter.data copies the results contained in Filtered Data Buffer into the clipboard. Cell R4C1 is selected and the values in the clipboard overwrite the raw data using the *Paste.Special* function. Cell R614C41 is selected before exiting *Filter.data* to display the graphs of the raw and filtered data.

It should be noted that the effect of *Filter.data* can be undone by invoking *Get.Data* to restore the raw data.

Filters for outputs of the room temperature sensor and low gain output from the pressure sensor can be inserted into Channel 4 of Filter Data by the macros *Insert.Temperature (ctrl T)* and *Insert.Pressure (ctrl p)*.

5.2.4 *Insert.Pressure (p)*

Invoking *Insert.pressure* results in copying the appropriate filter for the low gain output from the pressure transducer (located in column Z) into the clipboard and overwriting column M(Filter for Channel 4) in the Filtered Data area. The unused cell R1C13 is selected prior to exiting *Insert.Pressure* to avoid accidental deletion of the filter.

Insert.Pressure is used when both the high and low gain outputs from the pressure transducer are being logged. The low gain output is used to determine the static pressure at which the acquisition hardware is triggered whilst the high gain is used to determine dp/dt .

5.2.5 *Insert.Temperature (T)*

Invoking *Insert.Temperature* results in copying the appropriate filter for the room temperature sensor (located in column Y) into clipboard then overwriting column M(Filter for Channel 4) in the Filtered Data area. The unused cell R1C13 is selected prior to exiting *Insert.Temperature* to avoid accidental deletion of the filter.

Insert.Temperature is used when both the water and room sensors are being logged. The temperature sensors are used to determine \dot{T} and hence $\frac{\partial \phi}{\partial T}$ as outlined in the theory.

6. *Conclusions*

The theory of a measurement technique to obtain both the low frequency acoustic and thermal sensitivities of a fibre optic hydrophone has been outlined. An analysis program based on the theory was implemented in Microsoft Excel to obtain the pressure sensitivity of a fibre optic interferometric hydrophone transducer.

The technique is shown to delineate temperature and pressure effects by obtaining measured fringe frequency as a function of rate of change in pressure. A consequence of this is that the test system need not be in thermal equilibrium.

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Appendix A

Applications and Files for Data Analysis

The data analysis is carried out using three applications, File Manager of Windows 3.0, Microsoft Excel 3.0 and CA-Cricket Graph 1.2. The files used for the analysis by Microsoft Excel are C:\EXCEL\USER\HYDANAL.XLS, C:\EXCEL\USER\GETDATA.XLM and C:\EXCELDAT\EXDATA.

The spreadsheet, HYDANAL.XLS, and macro sheet, GETDATA.XLM are required to be open in Excel when the analysis is performed. Using File Manager, the raw data files are copied into the subdirectory C:\EXCELDAT and the file to be processed is then copied into the file EXDATA.

Switching to Excel, the analysis can be performed by invoking the Macro's Get.data and Extract.data to obtain a pair of data points $\left(\frac{dp}{dt}, \frac{d\phi}{dt}\right)$. These are copied into a table on the spreadsheet.

To process subsequent files we must switch back to File Manager and copy the next file into EXDATA and repeat the process. The result is copied into the next entry of the table.

After the data from a series of runs has been reduced to a table of data points $\left(\frac{dp}{dt}, \frac{d\phi}{dt}\right)$, the processed data is then transferred from the spreadsheet to CA-Cricket Graph for final curve fitting and presentation.

Appendix B

Filters

The filters employed in Filtered Data are five point sliding average filters. The averages are multiplied with the appropriate scaling constants and offsets. In columns J,K,L , the form of the filters are:

$$y_i = \text{scaling constant} * (y_{i-2} + y_{i-1} + y_i + y_{i+1} + y_{i+2}) / 5 \text{ for the interior points.}$$

At the end points the averages were modified to be weighted averages using the first and last five data points. These filters are of the form:

$$y_i = \text{scaling constant} * (3 * y_{i-1} + 5 * y_i + 3 * y_{i+1} + 2 * y_{i+2} + y_{i+3}) / 14 \text{ for the second point,}$$

$$y_i = \text{scaling constant} * (3 * y_{i+1} + 5 * y_i + 3 * y_{i-1} + 2 * y_{i-2} + y_{i-3}) / 14 \text{ for the second last point,}$$

$$y_i = \text{scaling constant} * (5 * y_i + 4 * y_{i+1} + 3 * y_{i+2} + 2 * y_{i+3} + y_{i+4}) / 15 \text{ for the first point}$$

$$\text{and } y_i = \text{scaling constant} * (5 * y_i + 4 * y_{i-1} + 3 * y_{i-2} + 2 * y_{i-3} + y_{i-4}) / 15 \text{ for the last point.}$$

The scaling constant for the third channel (column L, the optical output) is unity. The fourth channel required an offset. The filters were of the form:

$$y_i = \text{scaling constant} * ((y_{i-2} + y_{i-1} + y_i + y_{i+1} + y_{i+2}) / 5 - \text{offset}) \text{ for the interior points,}$$

$$y_i = \text{scaling constant} * ((3 * y_{i-1} + 5 * y_i + 3 * y_{i+1} + 2 * y_{i+2} + y_{i+3}) / 14 - \text{offset}) \text{ for the second}$$

$$\text{point, } y_i = \text{scaling constant} * ((3 * y_{i+1} + 5 * y_i + 3 * y_{i-1} + 2 * y_{i-2} + y_{i-3}) / 14 - \text{offset}) \text{ for the}$$

$$\text{second last point,}$$

$$y_i = \text{scaling constant} * ((5 * y_i + 4 * y_{i+1} + 3 * y_{i+2} + 2 * y_{i+3} + y_{i+4}) / 15 - \text{offset}) \text{ for the first}$$

$$\text{point and } y_i = \text{scaling constant} * ((5 * y_i + 4 * y_{i-1} + 3 * y_{i-2} + 2 * y_{i-3} + y_{i-4}) / 15 - \text{offset}) \text{ for the}$$

$$\text{last point.}$$

Appendix C

Code for Macros in GETDATA.XLM

Get.Data (d) =DIRECTORY("C:\EXCEL\DAT") =OPEN("EXDATA.") =SELECT("C1:C4") =COPY() =ACTIVATE("HYDANAL.XLS") =SELECT("R1C1") =PASTE() =COLUMN.WIDTH(...,3) =SELECT("R1C5") =RETURN()	Comments for Get.data select directory where data file resides Open data file select data columns and copy into the clipboard Change to worksheet and select home position paste data into worksheet format data column to best fit select r1c5 and return
Filter.data (f) =SELECT("R4C28:R603C31") =COPY() =SELECT("R4C1") =PASTE.SPECIAL(3,1,FALSE,F ALSE) =SELECT("r614c41") =RETURN()	Comments for Filter.data The Filtered data buffer is written into the raw data space. Hence the data can be fed through the averaging window a number of times. R614c41 is selected before exiting the routine, so that the relevant graphs are displayed.
Insert.Temperature (T) =SELECT("R3C25:R603C25") =COPY() =SELECT("R3C13") =PASTE() =SELECT("R1C13") =RETURN()	Comments for Insert.Temperature Filter for room Temperature sensor is selected from Filters and is copied into clipboard. Channel 4 in Filtered Data selected and Clipboard is copied into Channel 4. An unused cell is selected to avoid accidental deletion of the filter.
Insert.Pressure (p) =SELECT("R3C26:R603C26") =COPY() =SELECT("R3C13") =PASTE() =SELECT("R1C13") =RETURN()	Comments for Insert.Pressure (p) Filter for low gain pre-amp (x200) for the pressure sensor is selected from Filters and is copied into clipboard. Channel 4 in Filtered Data selected and Clipboard is copied into Channel 4. An unused cell is selected to avoid accidental deletion of the filter.

```

extract.phase (e)
=SELECT("R626C8:R1226C13")
=SET.DATABASE()
=SELECT("R626C15:R627C20")
=SET.CRITERIA()
=SELECT("R626C21:R826C22")
=SET.EXTRACT()
=SELECT("R627C19")
=FORMULA("<=0")
=SELECT("R627C20")
=CLEAR(3)
=EXTRACT(FALSE)
=SELECT("R627C19")
=CLEAR(3)
=SELECT("R627C20")
=FORMULA("<=0")
=SELECT("R626C23:R826C24")
=SET.EXTRACT()

=EXTRACT(FALSE)
=SELECT("R627C30:R1227C30")
=CLEAR(3)

=SELECT("R627C22:R826C22")
=COPY()
=SELECT("R627C30")
=PASTE()
=SELECT("R627C24:R826C24")
=COPY()
=SELECT("R927C30")
=PASTE()
=SELECT("R627C30:R1227C30")
=SORT(1,"R627C30",1)
=SELECT("r624c33")

=RETURN()

```

Comments for extract.phase (e)
Define data base of 1st and 2nd derivative zero crossing time estimates.
Select and set data extract criteria area

select and set first extract area

set condition of the first flag

delete condition of the second flag

and extract 1st derivative data
Clear condition of first flag and then

set the condition of the second flag

Set the extraction area for the 2nd derivative time estimates and extract the data

Clear time estimate column
Select time estimate data from 1st derivatives
and copy into time column

select time estimate data from
2nd derivative zero crossing estimates
and copy into time column

Select time column estimates and
sort into chronological order then select
select r624c33 so that graphs are visible
on exit

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TITLE

Implementation of Ramped Pressure Technique to Measure Acoustic Sensitivity of Fibre Optic Hydrophone Transducers

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Measurement Techniques

Fibre Optic Hydrophone

ABSTRACT

The theoretical and practical implementation of a measurement technique to obtain both the low frequency acoustic and thermal sensitivities of a fibre optic hydrophone is discussed. An analysis program based on the theory was implemented in Microsoft Excel to obtain the pressure sensitivity of a fibre optic interferometric hydrophone transducer. This method is based on ramping pressures at different rates. A major advantage of the technique is the temperature and pressure effects are clearly delineated and the test system need not be in thermal equilibrium.

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Sensitivity Fibre Optic Hydrophone Transducers

Eric C. Magi

(MRL-TN-657)

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