WOODS HOLE OCEANOGRAPHIC INSTITUTION

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SUBJECT: The ALVIN Heatflow Probe

1. Description

The heatflow probe is designed to provide a temperature profile from sea floor sediments. It also incorporates a heater to alter the steady-state temperature profile. By using these, sediment thermal conductivity and ocean bed heat flux can be calculated.

The probe itself is a slender titanium rod containing thermistors and heater element, and an attached electronics bottle. The probe can be interrogated through an RS-232 or RS-485 interface using a convenient, addressable communications format.

In addition, a DOS program, HEATFLOW, has been written to facilitate communications with and control of a heatflow probe.

To date, ten heatflow probes have been constructed. Probe serial number 1 is 1.0 meter in length; serial number 7 is 0.3 meters in length; the others are 0.6 meters in length. All have firmware version 2.3 installed. When constructed, all were configured with a Full-Duplex RS-232 interface at 9600 baud, 8 data bits, no parity, 1 start/1 stop bit.

Further documentation on these probes is contained in drawings A600106 "Smart Heat Flow Probe, Mechanical," A600107 "Remote Temperature Sense Module," and A600108 "Heat Flow Probe Tip Assembly (Short)." Copies of these drawings are provided in Appendix C.

2. Measurement Operations

It is important to drive the probe completely into the sea floor sediment; the electronics bottle end-cap should be at the sediment surface. After the probe is inserted into the sediments, about 20 minutes is required for a complete measurement: the first 10 minutes to measure the steady-state temperature gradient (and monitor the decay of frictional heating), and the second 10 minutes to measure the thermal conductivity.

7 + 7 is fine

There are two modes of use to determine thermal conductivity: constant heating and pulse heating. In the constant heating mode, the probe is used to measure the temperature rise for 10 minutes while the heat source is on. The rate of temperature rise is related to the thermal conductivity of the sediment; a faster temperature rise indicates less thermally conductive sediments. For pulse heating, a short pulse of thermal energy is added to the sediment (the calibration of the heater and the pulse duration determines the amount of energy added), raising its temperature. The rate of decay of this temperature rise is related to the thermal conductivity; a faster decay of the temperature profile back to its initial value indicates higher thermal conductivity.

Once the sediment conductivity is known, the temperature profile with distance from the sediment surface indicates the magnitude of the heat flux through the sediment.

Credit goes to Dick Von Herzen, Albert Bradley, and Ned Forrester for the conceptual, electrical, and software design of this instrument.

3. Probe Specifications

The probe tip is a titanium tube, 0.375" O.D. (Ti 6AL-4V, Grade V), either 0.3, 0.6 or 1.0 meter long, each containing five thermistors and a linear heater. The probe length, thermistor spacing and position, and heater characteristics are as follows:

Probe	0.3 Meter	0.6 Meter	1.0 Meter
Thermistor spacing	6.0 cm	10.0 cm	20.0 cm
Distance from point to first thermistor	7.3 cm	11.5 cm	10.0 cm
Heater length	34.5 cm	65.95 cm	100.0 cm
Heater extends beyond both ends of the thermistor array by at least	6 cm	10 cm	10 cm
Heater calibration	20.0 W/m	20.0 W/m	20.0 W/m
Heater dissipation	6.90 W	13.19 W	20.0 W

The probe tip is connected to an electronics bottle, 2.0" O.D (Ti 6AL-4V Ti, Grade V), approximately 15.5" long including the end caps and connector. This contains the control and interface circuitry of the instrument. The probe tip is attached to one end of the housing; the electrical connector is at the other.

The entire assembly has an air weight of approximately 5.5 pounds, a water weight of approximately 3.75 pounds, and an implodable volume of less then 14.5 cubic-inches. The differences between the 0.3, 0.6 and 1.0 meter probes change these weights only very slightly, and do not change the implodable volume.

4. Theory of Operation

The thermistors used are YSI (Yellow Springs Instrument Co., telephone number 513-767-7241) type 44032 NTC thermistors. These are describes as having a resistance of 30 KΩ at 25° C, and have an approximate resistance range from 800 KΩ at -40° C to 500 Ω at 150° C (although temperatures above 40° C may degrade the stability of the thermistors), and tolerance about ±0.1° C near 0° C.

The resistance of each thermistor is measured by timing the interval to partially discharge a capacitor (the thermistor and C1 form a timing circuit). Before each measurement, C1 is charged to 5 Volts through R3 and then allowed to discharge through the thermistor. Each measurement ends when the capacitor has discharged to about 2.5 Volts, as determined by comparator U2. Since the capacitor starts at the same voltage for each measurement, and is discharged to the same value for each measurement, the discharge time is proportional to the resistance being measured, while the value of the capacitor, the threshold voltage, and the timing units are all arbitrary.

In addition to measuring this time for the five thermistors in turn, the probe also measures the discharge time for two known resistors, of value 20 KΩ and 100 KΩ, both 0.1%. These two values correspond to about 35° C and -2° C respectively. IC U1 selects one of the thermistors or resistors to be measured. These seven times (in arbitrary units) are the primary data reported by the probe. By linearly interpolating the times for the five thermistors to the times for the two known resistors, the resistance of the thermistors can be found. From these resistances, the temperatures at each thermistor can be calculated using the Steinhart and Hart thermistor model:

$$T = \frac{1.0}{A + B(\ln R) + C(\ln R)^3} - K$$

where YSI's published parameters for the type 44032 thermistors are:

A = $935.4 \times 10^{-6}\ °C^{-1}$
B = $221.1 \times 10^{-6}\ °C^{-1}$

$C = 0.1275 \times 10^{-6}\ ^{\circ}C^{-1}$
$K = 273.15\ ^{\circ}C$

and:

R is the resistance of the thermistor in ohms
T is the temperature at the thermistor in degrees C

Another method of determining temperature from thermistor resistance is by interpolating through the look-up table of these thermistor's resistances, as published by YSI. This table appears in Appendix F.

The power dissipated in the linear heater is controlled by power FET Q1, which controls the current through the heater wire. This current is measured with resistor R22, whose voltage is compared to the output of DAC U6 by OP AMP U5. Resistors R17 and R18 and variable resistor R19 control the gain from the DAC to the FET. The heater is calibrated to 20.0 Watt/meter at full power by adjusting R19 while measuring the voltage across and current through the heater wire. With the heater set to zero power, the power dissipation through it is less than 100μWatt.

All of these operations are under control of microprocessor U3. U3 also performs all of the timing and external communications across either an RS-232 or RS-485 interface.

For safety reasons, the probe's electronics are protected by a thermal cutoff: if the probe's electronics temperature rises too high, the cut-off will stop supplying power to the heater. When the temperature has returned to acceptable levels, the heater will continue to operate. In addition, the probe's thermistors may loose calibration or fail if subjected to elevated temperatures. The heater will therefore cut-off if any individual thermister indicates a temperature above about 40° C. For this reason, it is recommended to run the heater only with the probe in cold water (for example, do not run in hot water or in air).

5. Electrical Interface

The electrical interface to the probe is through 4 conductors. These appear at the end of the probe on a Marshall (Marshall Underwater Industries, Inc., telephone number 515-549-3570) type 86-5FB (Female, 8-contact) connector:

Contact 1: +26 Volt Nominal Power
Contact 2: Ground
Contact 3: RS-232 Probe Transmit / RS-485 B
Contact 4: RS-232 Probe Receive / RS-485 A
The other 4 contacts of the E.O. connector are unused.

On this connector, contacts 1 and 2 appear in the first hole counterclockwise from the keyway, contacts 3 and 4 in the next hole counterclockwise from that. The contacts on the mating male connectors (either Marshall 26-5MC or 86-5MC) are odd-numbered at the tip and even-numbered at the ring.

The 26 Volt power requirement for the probe is less than 100 mAmps with the heater off, and about 1.5 Amps with the heater on. While the probe will operate correctly over the range from 22 Volts to 30 Volts for short periods of time, operation at no higher than 26 Volts is recommended.

Following ALVIN requirements, there is no electrical connection between any of the power or electrical signals and any of the metallic portions of the housing.

For RS-232 communications, the probe's two data contacts, 3 and 4, should be connected to the receive and transmit pins of a PC's COM port. (For 25-pin COM ports, these are pins 3 and 2 respectively. For 9-pin COM ports, these are pins 2 and 3 respectively.) Handshaking COM port's line RTS must be tied to CTS, and DSR, CD, and DTR must be tied together. (For 25-pin COM ports, these are pin numbers 4 tied to 5, and 6, 8, 20 tied together. For 9-pin COM ports, these are pin numbers 7 tied to 8, and 6, 1, 4 tied together.) Also, the COM port's ground line (pin 7 if a 25-pin COM port, pin 5 if a 9-pin COM port) must be connected to the probe's ground pin. These connections are shown in the following figures.

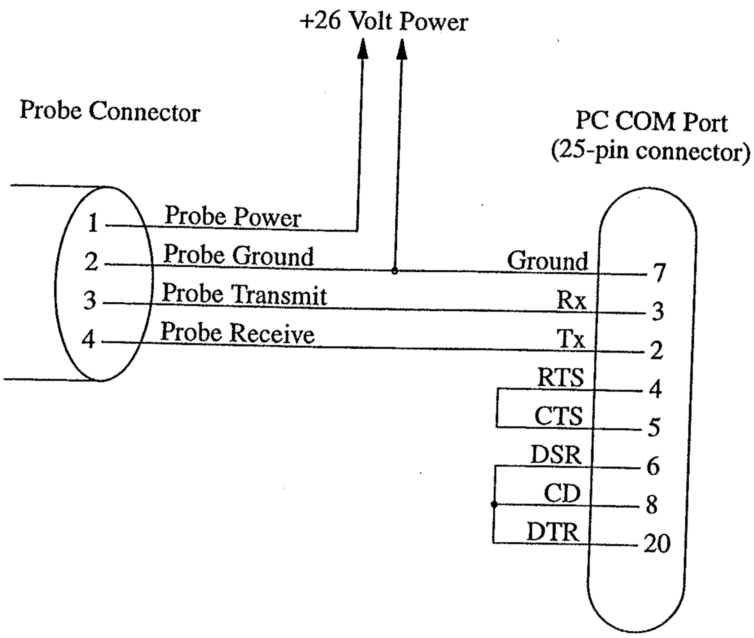

Figure 1. Wiring from Heatflow Probe to 25-pin COM Port

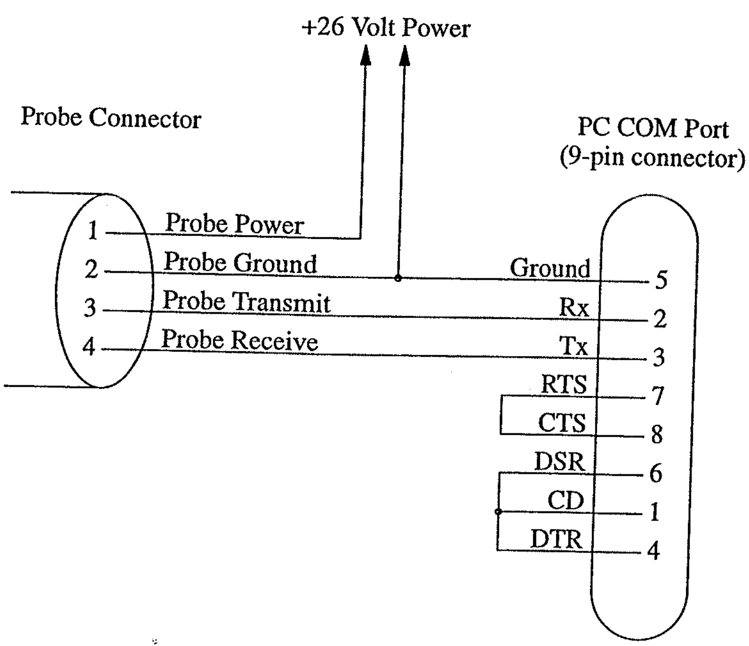

Figure 2. Wiring from Heatflow Probe to 9-pin COM Port

6. HEATFLOW Program

A DOS program has been written, called HEATFLOW, which aids in using the heatflow probe. This program communicates with the probe through a DOS-PC's COM port, converts the responses to temperatures in degrees C, and reports (and optionally logs) the results. HEATFLOW can also control the probe's heater in a flexible way.

The command line and parameter list for the HEATFLOW program is:

```
HEATFLOW <port> <logfilename> <loginterval> <heatdelay>
                              <heattime> <heatlevel>
```

where:

`<port>`	The COM port to use, either 1, 2, 3 or 4. The default is 1 for COM1.
`<logfilename>`	The name of the log file to write, or – for no logging. The default is to log to file heatflow.log.
`<loginterval>`	The logging interval in seconds. The default is 10 seconds.
`<heatdelay>`	The time in seconds after which to start heating. The default is 0 seconds.
`<heattime>`	The time in seconds to apply heat. The default is 0 seconds.
`<heatlevel>`	The heat level in the range 0-200. The default is 0.

and:

$$heater\ power\ level = (heatlevel/200)^2 * 20\ watts/meter$$

Each parameter is optional and can be omitted, as long as no subsequent parameters are needed. (For example, if `loginterval` must be supplied, so must `port` and `logfilename`, but `heatdelay`, `heattime`, and `heatlevel` may be omitted and will use the default values.) The command line is case-insensitive.

With these parameters, the HEATFLOW program can be used to automate a complete conductivity measurement. The command line could be:

```
HEATFLOW 1 heatflow.log 10 600 600 200
```

In this example, the program would sample sediment temperatures every 10 seconds (`loginterval` = 10) and log the samples into the file heatflow.log (`logfilename` = heatflow.log). This would be done with the heater off for 10 minutes (`heatdelay` = 600), then the heater would be turned to full power (`heatlevel` = 200), and temperatures logged for another 10 minutes (`heattime` = 600). This also assumes that the probe is fully inserted into the sediment, and that the probe is connected to port COM1 of the computer (`port` = 1).

Below is a sample output from the HEATFLOW program:

```
.
.
.
13:51:20 TT=0.027  T2=-0.055  T3=-0.048  T4=-0.009  TB=-0.087  H 0
13:51:30 TT=0.023  T2=-0.057  T3=-0.047  T4=-0.009  TB=-0.089  H 0
13:51:40 TT=0.019  T2=-0.057  T3=-0.049  T4=-0.010  TB=-0.092  H 0
13:51:50 TT=0.018  T2=-0.058  T3=-0.049  T4=-0.010  TB=-0.093  H 0
13:52:00 TT=0.016  T2=-0.059  T3=-0.049  T4=-0.011  TB=-0.092  H 0
.
.
.
```

For each interval (every 10 seconds in this example), the HEATFLOW program reports, from left to right, the time, the current temperatures of the five thermistors in degrees C, and the current heater value in the range 0-200 (here the heater is off). TT is the temperature of the top thermistor (near the electronics bottle), and TB is the temperature of the bottom thermistor (near the probe tip). T2, T3, and T4 are the intermediate thermistor temperatures from top to bottom. Note that for this naming, "top" and "bottom" refer to the positions with the probe inserted into ground sediment. If it is inserted into a wall or ceiling, "top" and "bottom" could be misleading.

As can be seen, this example was taken with the probe in an ice water bath, so all of the thermistors are registering near 0° C.

7. Low-Level Communications

While the HEATFLOW program can be used for most applications, some may require greater flexibility. For these, low-level communication with the probe is possible directly through the probe's RS-232 or RS-485 interface, as appropriate. On this interface, `#HF` is the probe's address, and all received characters are echoed. Note that since RS-485 is a multi-drop interface, several instruments can be on the same RS-485 line. Since all heatflow probes have the same address, though, only one heatflow probe can be on an RS-485 line.

The valid commands to a heatflow probe are:

`H` — Display a HELP message, including the probe's firmware version number and date. (Sending `#HFH` and getting a response is a quick way to check communications with the probe.)

`N` — Report the the probe's SERIAL_NUMBER. This command returns a space and a single hexadecimal character. For serial numbers ten or greater, only the ones digit is returned.

`T` — View the 7 current TIME_INTERVALS.
The probe's response to the T command is a space and 8 sets of four hexadecimal characters, separated by spaces. For example:

```
A138 A12F 207C 31F1 31F6 3629 372B 3902
```

shows the time interval values for the two resistors and five thermistors. The first number is to be ignored, the second is for the 100 KΩ resistor, the third is for the 20 KΩ resistor, and the fourth through eighth are for the top through bottom thermistors respectively. The last five values would be interpolated between the second and third to result in the resistances of the five thermistors. From these, the Steinhart and Hart thermistor model is used to calculate temperature. (These values all indicate near room temperature.)

`!Phh` — Set the heater POWER_LEVEL to the value `hh`. The `hh` value must be followed by a space. This command returns no response.

`S` — Report the current heater POWER_LEVEL. This command returns a space and two hexadecimal characters.

`!Qtttt hh` — Set the heater POWER_LEVEL to the value `hh` for `tttt` seconds. The `hh` value must be followed by a space. This command returns no response.

All of these commands are supported under version 2.2 or better of the microprocessor firmware. All but the N command are supported under version 2.1. This is the only difference between these two firmware versions.

On completion of a command, the requested activity is done immediately; no carriage return is necessary. All commands and parameters must be in upper-case characters. For commands requiring parameters, !P and !Q, each parameter must be in hexadecimal, of the correct number of characters, and followed by a <space>.

Heater power parameters, `hh`, are in the range 00 - C8, (0 - 200 in decimal). This corresponds to heater power from 0 to 20 watts/meter, where the two are related by:

$$heater\ power\ level = (hh/200)^2 * 20\ watt/meter.$$

Time parameters, `tttt`, are in the range 0000 - FFFF, (0 - 65535 in decimal). These values are in seconds.

Unless the instrument is configured for half-duplex communications, once addressed (`#HF` is received by the probe), the probe stays addressed until another device is addressed or until an unrecognized command is received. When addressed, the probe responds with a : (colon) as a prompt and an ETX (End-of-Text) character. This indicates that the probe has been addressed, and #HF is no longer necessary. Thus, from a colon prompt, the command alone can be entered. (Though it is not needed from a colon prompt, the prefix can always be used to start a command, however.)

8. Calibration, Configuration and Maintenance

As delivered from the vendor, the thermistors are already calibrated, so no adjustments are necessary there. Further, the design of the measurement circuitry is self-calibrating.

The probe's linear heater must be adjusted to dissipate 20 Watt/meter at it's maximum command setting. For the 0.3 meter probe, with a 34.5 cm long heater, this corresponds to a dissipation of 6.90 Watt, for the 0.6 meter probe, with a 65.95 cm long heater, 13.19 Watt, and for the 1.0 meter probe, with a 100.0 cm long heater, 20.0 Watt. To perform this calibration, the housing must be opened, and it is useful to have a tool which allows simultaneous measurement of the heater's current and voltage. This can be made of a short jumper installed between J1 and P1. If 8 of the 9 conductors are wired "straight through," a current meter can be installed in the ninth, being one of the two heater wires. A voltmeter can also be installed across the two heater wires.

While making the adjustments, the heater must be commanded to its highest setting. To both protect the thermistors and provide the most reasonable calibration, this should be done by supplying the proper nominal voltage into the probe and with the probe tip immersed in icewater.

There are many ways to command the heater to its maximum setting, but the easiest is to use the #HF!PC8 command. Once the heater is on, and while watching the heater's current and voltage, adjust variable resistor R19 until the heater power is the correct value. The adjustment on R19 is counterclockwise to increase power, clockwise to decrease.

The instrument can be changed from Full-Duplex to Half-Duplex by installing a shorting jumper in position W1. This prevents received characters from being echoed back.

The instrument's interface can be changed between RS-232 (as delivered) and RS-485. This is done by installing the IC associated with the necessary interface type (U4 for RS-232, U7 for RS-485), and removing the other one. In addition, the W1 jumper should be installed to force Half-Duplex communications. Otherwise, the echoed commands will be interpreted as new commands. As a result of this, the probe does not stay addressed after receiving the #HF address. The baud rate, data bits, parity, and start/stop bits can not be changed without a firmware modification.

Very little other maintenance is necessary beyond that normally associated with a deep-ocean instrument: a fresh water rinse after each immersion, inspection and servicing of the O-rings (including the one associated with the connector), and protection from shock.

9. Suggested Spare Parts and Accessories

It is recommended to have the following parts be available:

1. Two size 2-214 O-rings for use on the end cap and probe tip.
2. One size 2-015 O-ring for use on the connector.
3. O-ring lubricant.
4. Heat-sink compound.
5. IC CD4051 or equivalent (U1).
6. ICs MAX232 (U4) and 75176 (U7), only one of which should be installed at all times.
7. Shorting jumper for position W1.
8. A deck cable for running and testing the instrument in its housing. The supplied cable connects to the instrument through its underwater connector, and provides banana leads for supplying power to

the instrument and a 9-pin "D" connector for communications.

9. A deck cable for running and testing the instrument out of its housing. The supplied cable connects to the instrument through P2, and provides banana leads for supplying power to the instrument and a 9-pin "D" connector for communications.
10. A heater calibration cable. This cable fits between P1 and J1 and provides a convenient way to simultaneously measure heater voltage and current.
11. A copy of the HEATFLOW program, and a PC on which to run it.

10. Firmware History

There are three current versions of probe firmware. Each one provides a superset of functionality over the previous. Versions 2.2 and 2.3 provide minor enhancements over version 2.1.

10.1 Version 2.1

This code is dated July 19, 1990. It provides complete heatflow probe functionality. The complete set of Low-Level commands (described above) is supported, with the exception of the #HFN command to report the probe's serial number.

10.2 Version 2.2

This code is dated March 30, 1992. This version supports all of the functionality of version 2.1, with the inclusion of the #HFN command.

10.3 Version 2.3

This code is dated March 1, 1995. This version provides all of the functionality of versions 2.1 and 2.2, and has better support for RS-485 communications.

11. Software

The source listing of the Version 2.3 microprocessor firmware (HEATFLOW.ASM) is provided in Appendix D. The source listing of the HEATFLOW program (HEATFLOW.C) is provided in Appendix E. A floppy disk containing these source codes, the HEX file of the microprocessor firmware (HEATFLOW.HEX), and the executable form of the HEATFLOW program (HEATFLOW.EXE) can also be provided.

It should be noted that the probe serial number (the response to the #HFN command), is coded into the firmware, so a specific HEATFLOW.ASM file and it's associated HEX file are only appropriate for a single probe.

12. Data Sheets

Data sheets for several of the major components have been included in Appendix F.

13. Fault Modes

There are three primary fault modes that have been identified with the heatflow probe. Whereas some component failures would obviously result in complete failure of the instrument, under these three, the instrument continues to operate, but at an unacceptable level of accuracy.

13.1 PC Board Silkscreening

As a result of an error during manufacture of the printed circuit boards, the component silkscreening was applied to the wrong side of the board. Because of this, though it indicates the correct component locations, it is printed in mirror-image. While this is not really a probe fault mode, it is included here for completeness.

13.2 Power Supply Noise

It has been found that the MAX232 device (U4), which converts logic levels to RS-232 levels, can contaminate the instrument's 5-Volt power supply. This device contains an internal switched-capacitor power converter that operates at about 30 KHz. While the noise seen is small enough that it doesn't effect the microprocessor or logic functions, it is enough to effect the C1 discharge timing, since the timing stops when the capacitor voltage drops below one-half of the 5-Volt supply. With noise on the 5-Volts, that timing could be stopped too early or too late.

This fault is repaired by providing an extra 5-Volt regulator, U10, in parallel with the primary regulator, U9. This secondary supply, called +5R, is used to power the RS-232 and RS-485 components only. Now, this noise is contained to the 5VR line, and does not contaminate the power supply used for timing.

Once this fault was identified, all of the existing probes were modified, and all subsequently constructed probes were built with the modification.

13.3 Thermistor Failure

Thermistors can fail, usually due to either shock or exposure to elevated temperatures. The fine wires leading to the thermistors can also break if mishandled. If either of these is the case the thermistor will read open, causing that channel to look like an infinite resistance, and results in an FFFF time interval. This corresponds to very small temperature.

The repair of this fault is to open the probe tip assembly, carefully remove the heat-shrink tubing holding the assembly together, replace the thermistor and the tubing. It is best to remove only those pieces of heat-shrink tubing that cover the particular thermistor being repaired. Absolute care must be taken not to damage the fine wires leading through the assembly or to alter the relative locations of the thermistors.

13.4 Multiplexor Failure

There has been a failure of the CD4051 analog multiplexor device, U1, which resulted in bad thermistor measurements. This was the result of extra resistance in the multiplexor changing the C1 capacitor charging and discharging current, and hence the time. This fault was identified by some or all of the thermistor channels reporting obviously incorrect temperatures, such as can be seen in open, cold water.

The repair of this fault is to replace the 4051 IC.

Appendix A: Heatflow Probe Housing Disassembly & Assembly

The heatflow probe housing can be disassembled with the following steps:

1. Loosen and remove the three 8-32 screws holding the end-cap (with the E. O. connector) to the housing.
2. Carefully pull the end-cap straight off, being sure to not damage the O-ring or O-ring sealing surface.
3. Pull the end-cap away from the housing a few inches. This will expose connector J2.
4. Disconnect this connector. Its pins are quite small, and can be bent easily.
5. Loosen and remove the six 8-32 screws holding the probe tip to the housing.
6. Carefully pull the probe tip straight off, being sure to not damage the O-ring or O-ring sealing surface. The probe electronics card is attached to probe tip, so continue to pull the electronics straight out of the housing.
7. Completely clean off the heat-sink compound from around the heatsink and from the inside of the housing.

To reassemble the instrument:

1. Inspect and service the probe tip's size 2-214 O-ring and its sealing surface. The O-ring should be coated with a LIGHT film of lubricant. Note that the probe tip end of the housing has six screw holes.
2. Slide the probe electronics, already mounted to the probe tip, into the housing, taking care to not catch any of the wires between the circuit card and the housing. The fit is tight, but the electronics should slide freely.
3. About two inches before the probe tip is seated, apply from the end-cap end, a coating of heat-sink compound around the inside surface of the housing. By applying the compound in this way, it does not get smeared along the entire inside length of the housing, as it would if the compound were applied directly to the heatsink.
4. Press the probe tip onto the housing.
5. Install and evenly tighten the six 8-32 screws holding the probe tip to the housing.
6. Inspect and service the end cap's size 2-214 O-ring and its sealing surface. Be sure that no heat-sink compound is left on the sealing surface. The O-ring should be coated with a LIGHT film of lubricant. Note that the end cap end of the housing has three screw holes.

   Reach into the housing and pull out connector J2. Attach the end-cap to this connector.
7. For highest reliability, the housing should be purged with a dry gas, such as nitrogen, to displace moisture around the circuit.
8. Carefully coiling up the wire, press the end cap onto the housing.
9. Install and evenly tighten the three 8-32 screws holding the end-cap to the housing.

With the probe housing disassembled, the probe tip can be disassembled with the following steps:

1. Cut the lacing and/or tie-wraps holding the tip wiring in place. The wires leading to the probe tip are enamel coated, so they should be bent as little as possible.
2. Disconnect connector J1.
3. Loosen and remove the two 6-32 screws holding the circuit card to the probe tip.
4. Remove the PC board clamp, allowing the probe tip to come completely away from the circuit card.
5. Loosen the Swagelok cap through which the wires pass. Be sure to not allow the wires to rotate while the Swagelok cap is being turned. This could damage or even twist off the thermistor wires.
6. Holding the probe tip vertically, carefully withdraw the thermistor assembly from the probe tip. Since the tube is filled with caster oil, this step can be messy.

To reassemble the probe tip:

1. Holding the probe tip vertically, fill the tube with caster oil. Since the thermistor assembly will partially fill it, the tube does not have to be completely filled at this point. Heating the oil may allow it to flow into the tube more easily. Further, gently heating the tube with a heat gun may also help.
2. While holding the thermistor assembly straight above the probe tip, slowly lower the assembly into the probe tip. Lower it a small distance at a time to allow the oil to flow between the wires and heat-shrink tubing. Several times during this operation, heating the tube slightly with a heat gun (but do not overheat the thermistors) can help to dislodge air bubbles, allowing them to rise up and escape. This step can be extremely messy.
3. Just before the thermistor array is fully seated, fill the probe tip with caster oil to just below the conical portion of the Swagelok fitting.
4. Tighten the Swagelok cap onto the fitting. Be sure to not allow the wires to rotate while the Swagelok cap is being turned. This could damage or twist off the thermistor wires.
5. Reassemble the PC board clamp around the thermistor wires.
6. Reassemble the circuit card on to the probe tip using two 6-32 screws. The circuit card must be centered onto the probe tip for it to properly slide into the housing.
7. Reapply any lacing and/or tie-wraps that were removed.