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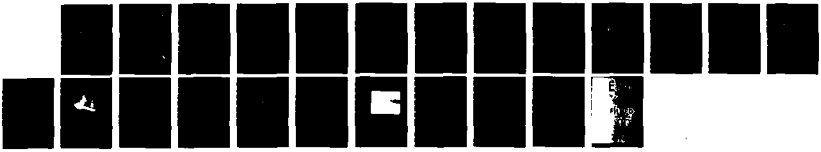

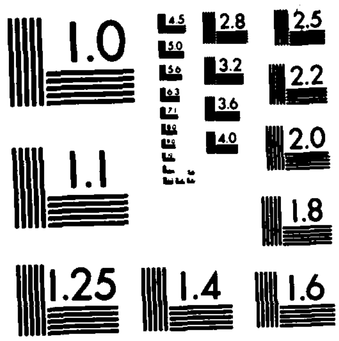

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PRODUCTION OF HOT-WIRES

BY

STUART C. DICKINSON

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PRODUCTION OF HOT-WIRES

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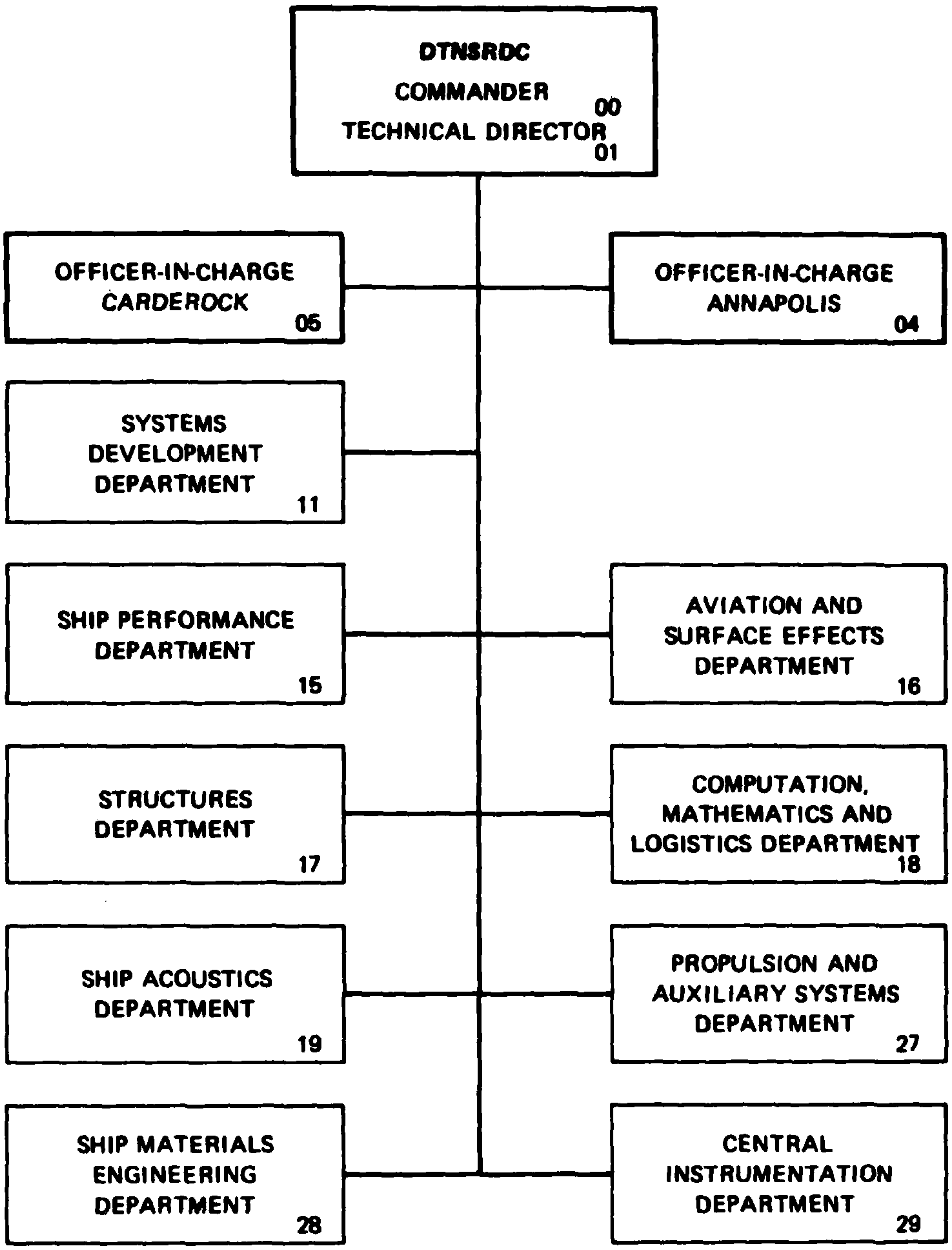

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ABSTRACT

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ADMINISTRATIVE INFORMATION

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INTRODUCTION

Hot-wire probes are, in general, simple devices. But when they are miniturized to reduce interference effects, achieve high frequency response and small spatial resolution, they become small fragile sensors. Most users, consequentially, have found commercial hot-wire probes to be the most convenient and economically justifiable. However, the ability to produce and repair probes can be important to the researcher in a fluid mechanics laboratory. A researcher has greater flexibility in geometries and placement of probes in addition to quick wire replacement in case of breakage. Such devices as vorticity probes, hot-wire rakes, and wire support prongs mounted in the model itself are not standard configurations offered by commercial manufacturers, and are best manufactured by the user.

Sensor replacement is quick for simple probes. To replace a single wire takes the author approximately twenty minutes including set-up time. Especially when one is working close to a solid boundary -- e.g., in the inner regions of the boundary layer -- wires get broken frequently, making self replacement handy. Contaminated flows also require frequent wire replacement. With custom-made probes it is expensive to own several probes, so the ability to replace sensors oneself is valuable.

This report describes several methods of producing probes and attaching wires (the calibration and use of hot-wires is not discussed). The process is not difficult once mastered, although practice is required initially. Most people have the ability to produce hot-wires. The primary limiting factors are good eye-sight, relatively steady hands, and patience.

PRODUCTION OF HOT-WIRES

Probe & Wire Support

First one needs to obtain or construct the support for the sensor wire. The body of the probe can be made out of a ceramic tube with two or four holes formed in it. Often these tubes are scavanged from thermocouple wire assemblies.* A manufacturer should be located.

The needles that support the hot-wire are often jewelers' broaches. Dr. Maxey uses in producing his supports #12 BR460 Round (BR 470 should work also) which are obtained from Royal Tschantre in Baltimore, Maryland. They are a "large" broach with the diameter slightly larger than the holes in the ceramic support tube.

First measure the length then break off a small section of ceramic tube. The broaches are inserted from the back so the thin needle ends protrude out the front. This gives a taper fit which should provide good positioning in probes for which four prongs are desired in a square array. The broaches can then be glued in place (epoxy works well).

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* From talk with Dr. Martin Maxey, May 1981, in Professor S. Corrsin's Laboratories at The Johns Hopkins University

The hot-wire gets attached to the needle ends and the "fat" ends have leads soldered to them. After the leads are insulated, the ceramic tube can be inserted in a metal tube of appropriate inside diameter. The result should be a sturdy probe body. The prongs can then be trimmed and bent as needed for the particular application. Bending should be held to a minimum, however, as the broaches are somewhat brittle.

A second method used in Professor L.S.G. Kovasznay's Laboratory was to use a dental cement (pinkish in color - epoxy putty would be a good substitute) and glue the prongs directly in the metal tubes. Problems with this method are preventing shorts and holding the broaches in alignment while the glue sets. Probes built this way have survived twenty years' use, so the technique works.

The prongs can be made from different materials. The jewelers' broaches are perhaps the most common; however, the author has heard of ordinary sewing needles being used. Most any needle-like support could be used as long as there is a good way to attach the hot-wire, and one can solder the leads to the back ends. Jewelers' broaches are made of steel. These take the solder well if properly cleaned (fine emery paper) and fluxed. The steel rusts, however -- a result of handling and the acid fluxes used -- so a good sanding with 300 - 600 grit emery paper is recommended before mounting a new wire. TSI and DISA gold plate thin probe needles prevent corrosion and provide a good surface for soldering. The rust is no real problem, but one could easily copper or gold plate the support needles. Structurally the needles must be strong enough to not deflect under the aerodynamic loads of the flow, or shocks due to normal handling. Flexing of the prongs will break the wire. A compromise must be made between the strength and the flow blockage of the supports.

Wire Preparation

There are three distinct types of wires -- two platinum and one tungsten. Common to all three is a large aspect ratio -- the sensor portion of the wire should be approximately 200 times longer than its diameter. The wire should be strong enough to withstand the aerodynamic loads at the temperature used, and should have a good temperature coefficient of resistance.

The first type of wire is the bare platinum sensor. This wire involves no preparation and is typically spot welded to the support prongs. Using this technique, extremely small probes can be constructed, and most of the subminiature probes are of this construction. Construction of this type of hot-wire is considered difficult, and since the author has no experience with it, it will not be discussed further.

The most common type of wire is plated tungsten. The wire is strong and easy to attach to the prongs by soldering. The wire is basically a bare section of tungsten — the sensor portion -- with copper or platinum plated sections on each end. The plating defines the sensor length and provides a material to which the solder will easily adhere. A typical wire size is .00015" (3.7 μm). Preparation consists of plating the bare wire on both sides of a fixed-length sensor portion. A plating device designed in Kovasznay's lab used copper sulfate ($CuSO_4$) and an electrical current to generate uniform wires (see Figure 1). A whole string of sensors can be produced, then cut apart and mounted. The TSI probe catalog says that they plate their sensors with platinum; however, their card of replacement sensors comes as copper-plated tungsten. An optimal plating current exists and is maintained for approximately one minute. The object is to create an even coating on the wire thick enough to conduct well but not so thick as to cause structural problems at the interface by being overly stiff.

The last type of wire uses a platinum sensor. The wire is made by the Wallaston process. This allows smaller diameter wires to be made. The Wallaston wire is platinum with silver plated on it. This "sandwich" is then pulled into thin wire allowing the core to be much thinner than would normally be possible. First the wire is soldered on to the support and then the silver coating is etched off to create the sensor area (see Figure 2). To etch, a burrette with a special nozzle is used to create an even jet of 20% Nitric Acid (HNO_3). At Johns Hopkins (Corrsin's Lab) the burrette (titration tube type) was made in the Chemistry Department glass blowing lab. A platinum anode is

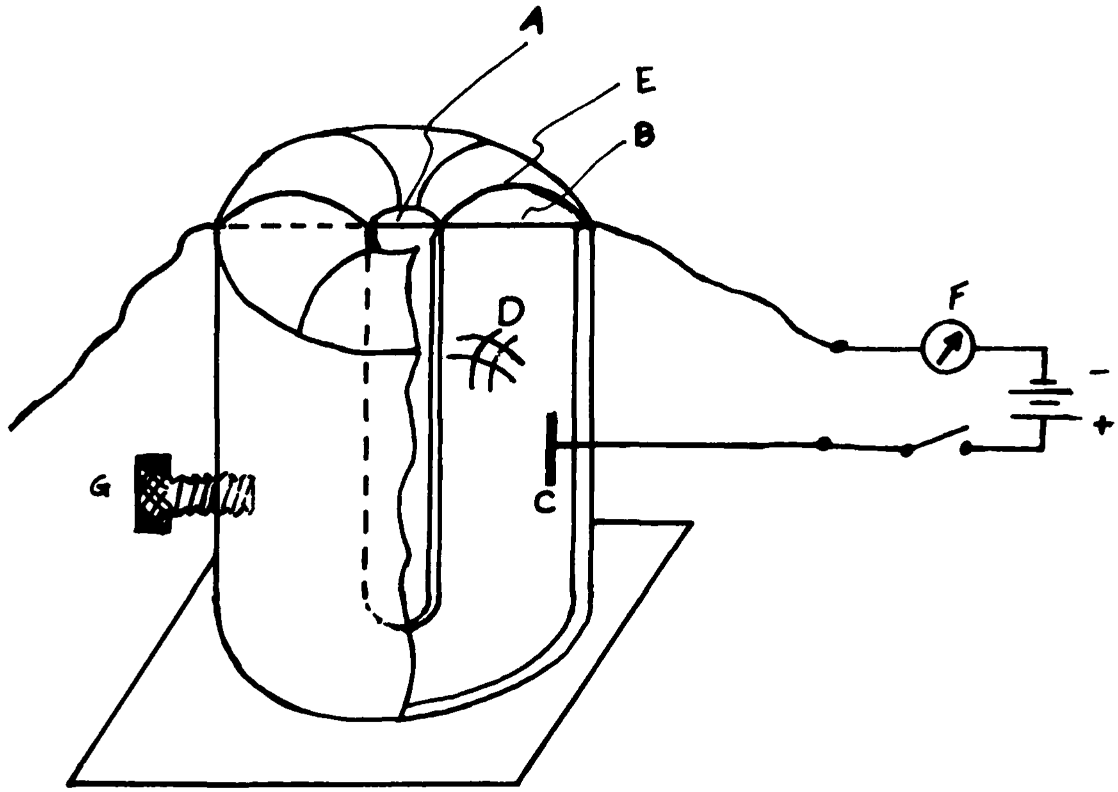

Figure 1 - Copper Plating Device

A. Sensor Portion of Wire (Not Plated)
B. Plated Portion of Wire - Cathode
C. Copper Anode
D. Copper Sulfate Solution
E. Electrolite Being Held by Surface Tension
F. Ammeter
G. Electrolite Height Adjustment Screw

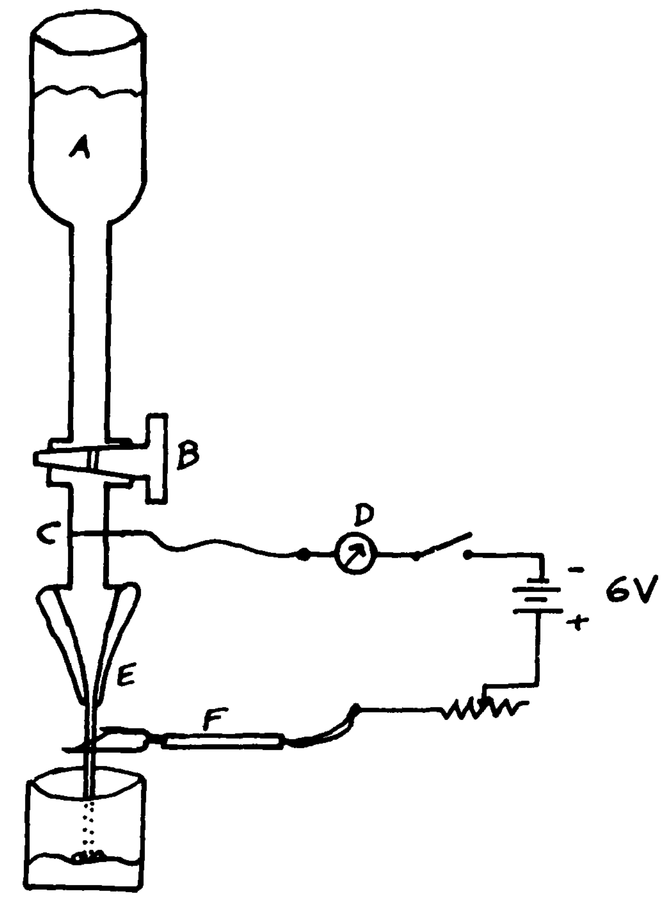

Figure 2 - Wire Etching Apparatus

A. Nitric Acid (20%)
B. Stopcock
C. Platinum Cathode
D. Ammeter
E. Nozzle
F. Wire Being Etched - Anode

inside the burrette. The bottom ends in a ground glass joint. Two nozzles are used with a 1.0 mm, and a 0.5 mm bore respectively. The nozzles were manufactured by B&R Instruments, Ritchie Highway, (Maryland, Route 2) and fit the ground glass joint. The 1.0 mm jet is used with .0002" (5 μm) wire (platinum portion) for hotwire sensors and the 0.5 mm jet is used with .000025" (0.6 μm) wire for temperature wires (low current - constant current mode). The soldered wire is placed in the acid jet and the hot-wire is hooked up as the negative electrode. A 0.3 m A current is used. The current will drop when the wire is etched (or broken), usually after 1 minute. The laminar portion of the jet must be used for etching.

Positioning the Wire

There are two basic ways to attach a wire to the support prongs - spot welding and soldering. Both of these methods, however, require a way to support the probe and the wire and to position them during the attachment process. The wires should be mounted on a "frame" to allow handling. The best method is probably a copper wire "Y". On the end of each prong is a blob of beeswax over which the wire is draped. An old soldering iron (warm) is then used to melt the wax - which holds the wire (see Figure 3). The wire should be loose between the prongs. Also a device is needed to position the wire on the needles and hold it there for soldering or welding. The positioning and soldering is usually done under magnification -- one should really use a sterioscope. A sterioscope shows some depth of field -- a three dimensional image -- and the image is reverted; i.e., motion to the right moves the image in the same direction. To manipulate the wire to the probe (or vice versa, it makes no difference) a X-Y traverse is really needed. Positioning can be done just with adjustable clamps such as those supplied with the TSI Sensor Repair Kit, but one will probably break many more wires. A screw-type micrometer traverse on the X-Y is desirable; and on one axis, almost necessary. The X-Y should be set up with one axis vertical and the other in and out. Side to side (parallel to the wire)

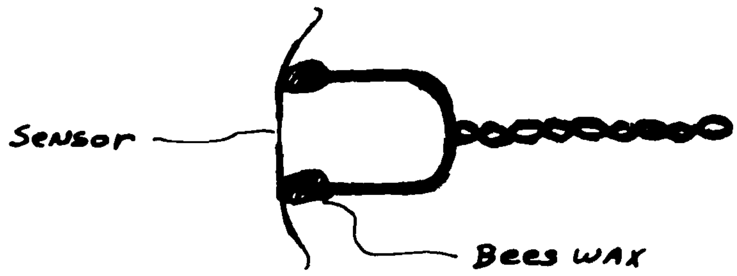

Figure 3 - Wire Holder

positioning can normally be achieved by sliding the whole arrangement on the table top. If one has access to a X-Y-Z and rotate traversing table, the job is even easier. The actual arrangement should be tailored to the person doing the work. With practice and a steady hand, complicated probes can be assembled with minimal equipment. For multi-wire probes the better manipulator arrangements are worth the effort expended in constructing them. The author likes to use an arrangement mounted on an optical bench (wire & probe), so if something gets bumped the whole apparatus moves together. (See Figure 4 for the author's system).

The wire needs to be placed on the probe gently and without stretching. There are normally two positions for the wire: laid on top of the prongs or attached to the end of the prongs (see Figure 5). The end attachment works if the prongs are squared off -- most commercial probes are assembled this way. With jewelers' broaches or sewing needles, however, the "laid on top" position is the best and does not affect the accuracy of the probe if mounted near the ends. For the plated sensors the bare wire should be between the support prongs and centered as much as possible. When the wire is placed on the prongs it should touch both prongs at the same time without deflecting the prongs or stretching the wire. If the wire is stretched it will break easily and will also function as a strain gauge. To get the wire on both prongs simultaneously, either the probe or the wire will have to be rotated slightly. The slack in the wire when mounted on the "Y" will make this process easier. (In the author's opinion the sensors on the TSI replacement card are strung too tight.) Now if the probe is prepared one can attach the wire.

Attaching the Wire

Soldering is the most common technique for attaching the wire. Most of the work is done before the wire is placed on the probe.

Preparing the probe is easy but must be done carefully to achieve a good joint. First the ends of the prongs must be sanded (with 300 - 600 grit emery) removing all rust, dirt and other contaminants. It is a good idea then to rinse

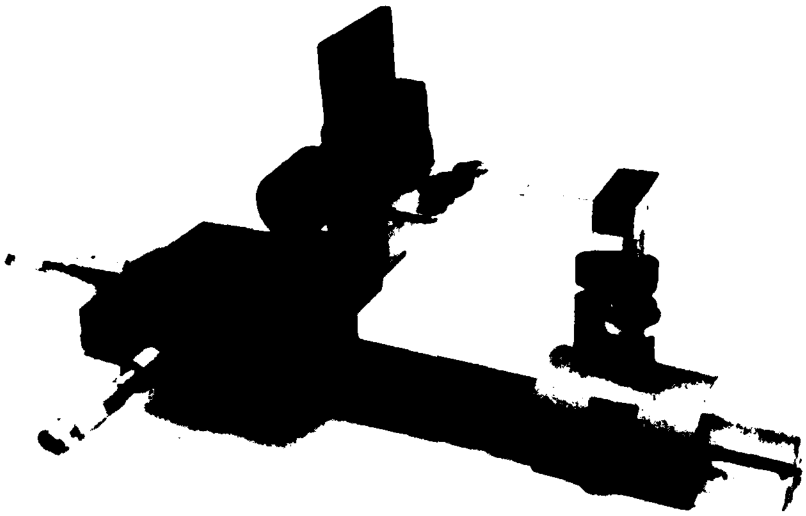

Figure 4 - Author's Positioning System

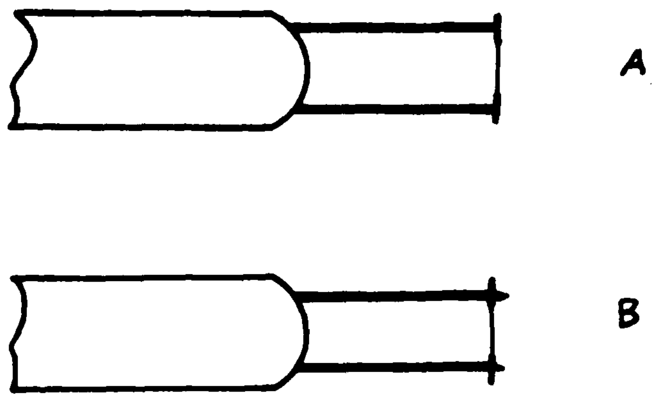

Figure 5 - Positions of Wire Attachment

A. On Ends of Prongs
B. On Top of Prongs

the probe in alcohol to remove any oils from handling (a fine brush works well). Next the probe tips should be fluxed with sulfuric acid flux. Fluxing can be done by dipping just the ends of the probe in the acid, using a needle or broach to apply a drop to the tips, or else using a pipet dipped in the acid and inserting each prong into the end. A clean soldering iron should be used to "tin" the prongs. A damp sponge is a good iron cleaner; however, if the iron tip has oxidized badly, sanding may be necessary. 400° strain gauge solder works best because it has a higher melting point than regular solder. However, any good solder (without internal flux) can be used if the wire is to be run at moderate overheat. The soldering iron should be "cool" -- just hot enough to melt the solder well. Now tin the tip of the probe keeping the solder just in the area where the wire will be mounted. The wire is then placed on the probe as described in the previous section. Very carefully touch the soldering iron to the prong back towards the base of the needle until the solder at the wire melts and attaches the wire. Do not deflect the prong with this process -- you can use a drop of solder on the iron to keep from touching the needle with the iron itself (see Figure 6). Now do the other side.

Another method is to touch the wire itself with a tiny drop of solder on a minature iron tip, being careful not to allow solid-to-solid contact. If this method is used, remove the iron laterally (parallel to the wire) to avoid pulling the wire off the supports by surface tension. This drop method is probably necessary if two or more wires are being soldered to the same prong (e.g., vorticity probes).

Cutting the Wire

This is the most delicate part of mounting a hot-wire sensor, since at this time one must make firm mechanical contact with the soldered wire. The most important element is to have a sharp knife. Many people use single edge razor blades, but the author prefers a normal two edged shaving blade since they are considerably sharper. One side of the blade should be taped for safety. When cutting the wire always cut toward the probe body parallel to and as close to the prongs as possible. When cutting be careful not to deflect the prongs as this will usually break the wire. Carefully remove the wire holder.

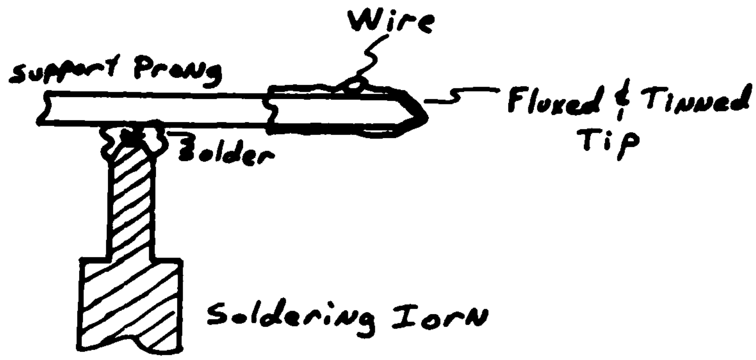

Figure 6 - Soldering Technique

Examining the Sensor

Before removing the sensor from the manipulator, examine it under the microscope. Check for good solder joints. Check for broken wire. There should be some slack in the wire, .001" - .002"; however, much more slack and the wire will oscillate in the flow and give a spurious signal. Remember also that the wire will elongate when heated. If the wire is too tight try loosening it by reheating the solder on one prong which should allow the wire to relax when it melts. What if the wire is broken? There are three ways to check for a broken sensor: visually, mechanically, and electrically. Visual inspection is performed under a microscope as mentioned above. The best mechanical method utilizes a human hair. Pluck a hair and holding only one end, lean it against the wire. If the wire is whole the hair will bend; however, if the wire is broken the hair will almost magically pass right through. Electrically the method is by a resistance check. Be sure to use a good high impedence ohm meter. Most normal volt-ohm meters use too much current to measure the resistance and will burn out the sensor almost immediately. Or one can use the resistance bridges in the anemometer in a null circuit as described in the manufacturers' instruction manual.

Washing the Sensor

An acid flux is used during the soldering and must be washed off. If left it will cause the solder joint to deteriorate with time and also rust the support prongs. A solution of distilled water and baking soda should be made and the probe swished around to neutralize the acid. Then the probe should be rinsed in distilled water and finally in clear alcohol to remove any oils from handling. Some people like to use a small brush (on the prongs only) during washing. Just swishing the wire around in the water; however, works as well and involves less risk to the wire.

The probe is now ready to be calibrated and used. Figure 7 shows a Kovasznay-type vorticity probe built by the author.

Figure 7 - Vorticity Probe Built By Author
(Magnified Three Times)

DISCUSSION

The production of hot-wire probes is straightforward and achievable by most fluid mechanics research scientists or technicians. This report is essentially an instruction manual covering several methods of probe production and sensor replacement.

Custom probes can be produced by the basic methods discussed herein with modifications up to the individual. Within the constraints of an experiment, probe configurations are limited only by the imagination of the user.

ACKNOWLEDGEMENTS

I would like to thank Dr. Martin Maxey for his explanations and tour of the hot-wire facilities in the laboratory of Professor Stanley Corrsin at The Johns Hopkins University. Also thanks go to Dr. Chih-Ming Ho who taught me how to copper plate and solder hot-wires while I was an undergraduate at The Johns Hopkins University. Special memories go to the late Professor Leslie S.G. Kovasznay, who explained the functioning and use of the hot-wire anemometer clearly enough for me to understand.

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