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AMATEUR YACHT RESEARCH SOCIETY

AYRS

COMPUTERS AFLOAT

An Introduction to Data Acquisition for Yacht Research

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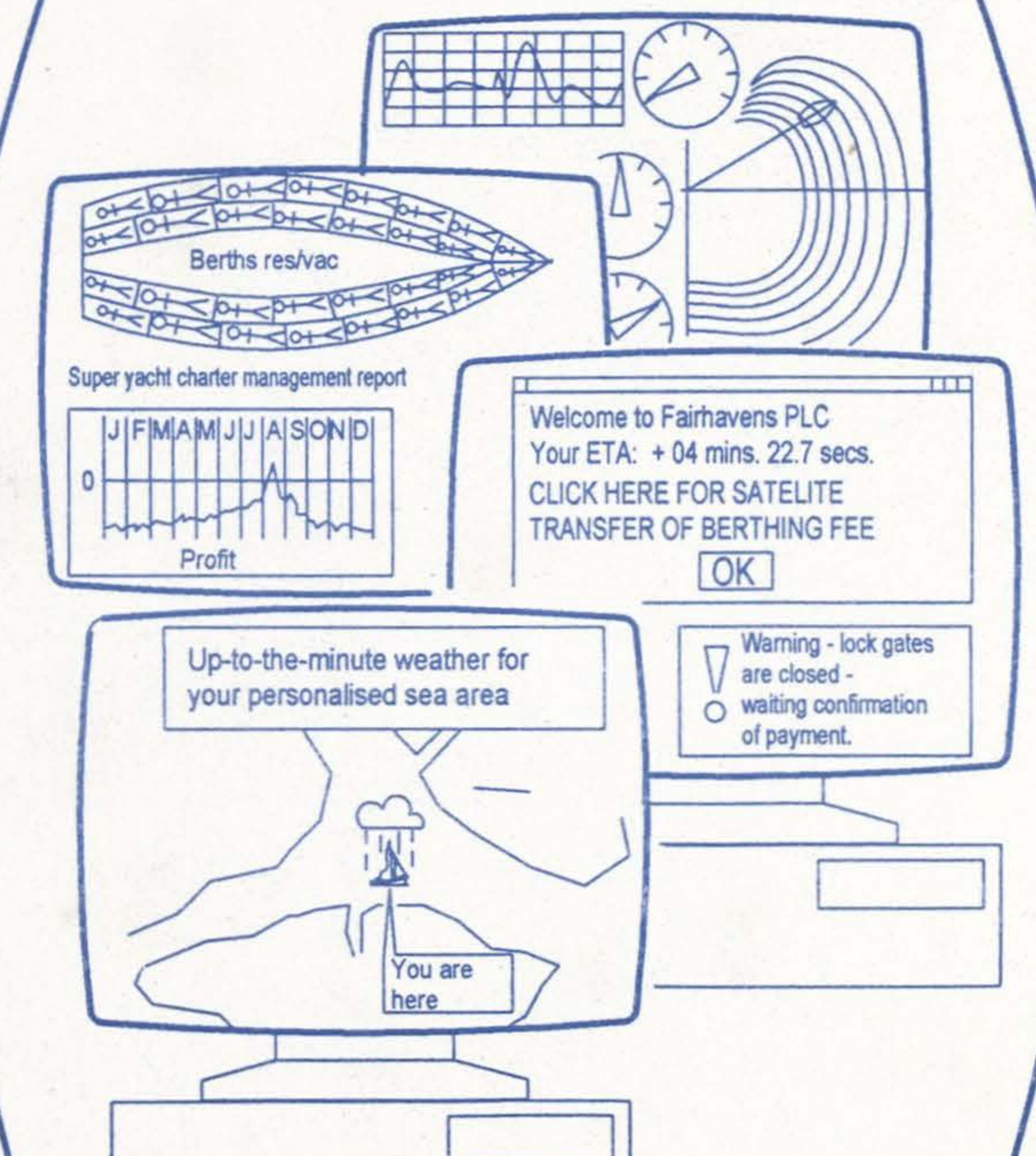

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1. INTRODUCTION

This booklet is an introduction to the use of computers for recording and processing experimental results, particularly with reference to yacht research projects. This application of computers is known as data logging, data acquisition or sometimes DAQ for short.

I would say at the outset that I am not particularly well qualified to write this booklet having never used any kind of electronic measuring instrument on board a yacht, not even an echo sounder (the centreboard frequently serves this purpose). Neither am I an electronics engineer but I do have some experience of using instrumentation systems in industrial research and development. It may well be that other AYRS members have more relevant experience of such systems in yacht research in which case I am sure that their contributions to AYRS publications would be most welcome.

A fair number of AYRS members now own a computer and this number can be expected to increase in the future. If you already own a computer then the additional cost of the parts necessary to use this computer for data acquisition can be less than the cost of the computer itself and so this option is now accessible to many amateur researchers. Having said that, I would not wish to discourage those whose budgets will not cover the cost of a computer; there is plenty of interesting yacht research which can be completed without using instruments, let alone without using a computer.

Because this is a short booklet some details have been skipped and anyone assembling an instrument system for the first time would need to supplement this booklet with further information on simple electronics and computer programming. These subjects are well covered by textbooks available from public libraries and from suppliers such as Maplin (see Section 12). They are also popular subjects for evening classes run by local colleges.

2. WHY USE A COMPUTER IN AN INSTRUMENT SYSTEM ?

The advantages of computer based instrument systems are the ability to take readings in large numbers and at high speeds and the convenience with which the results can be stored, processed and displayed. These advantages are not insignificant, and, once one has used a good computer based instrument system, one is likely to be unwilling to change back to reading dials and noting down the readings on paper, perhaps followed by hours of manual calculations and graph plotting. However, it is important to remember that the addition of a computer to an instrumentation system will not necessarily improve accuracy, although it is true that the ability of a computer to record huge numbers of readings and then average out of the results can sometimes reduce the effect of random errors.

To provide the uninitiated with an idea of what is implied by large numbers of readings, let us suppose that you are taking readings from an instrument panel in the traditional manner of men in white coats, holding a pad of paper on a clipboard whilst squinting at a bank of flickering dials and trying to note down some representative numbers. I suppose that you might be able to write down ten or twenty readings in a minute, although if there are a number of dials to track, you will probably soon get in a muddle and make mistakes. A computer can make a big improvement to this kind of operation. A quite ordinary computer connected to an instrument system can take thousands of readings every second and if required to do so it could continue until the hard disc is filled, by which time typically hundreds of millions of numbers will have been recorded without a single mistake being made. The problem is no longer to get sufficient data but is to pick out the useful information which may be hidden amongst a bewildering mass of numbers.

Note: This publication concentrates on the use of "general purpose computers" by which is meant the IBM PC and equivalents. Users of Apple Macintosh and other general purpose machines will find much that is applicable to them, although they should bear in mind that connection details etc. will be different, and that the range of available peripheral cards will be different also.

It should be noted that a number of older "home computers", for example the Acorn BBC, and other machines of a similar era (late 1970s) had built in interfaces for attachment to instruments and other electronic systems. Although such machines are considerably less powerful than modern PCs, they may be more than enough to handle data gathering, leaving the "number crunching" to modern computers with a better range of graphical outputs.

3. OVERVIEW OF TYPICAL SYSTEM

A computer standing on its own cannot make measurements, other than time measurements based on the real time electronic clock which is a feature of all modern general purpose computers. To measure physical quantities such as speeds, angles, distances, forces and many others the computer needs to be part of an instrument system, which would typically be arranged as shown in Figure 1 below, and which includes sensors, signal conditioning circuitry, an interface unit and the computer.

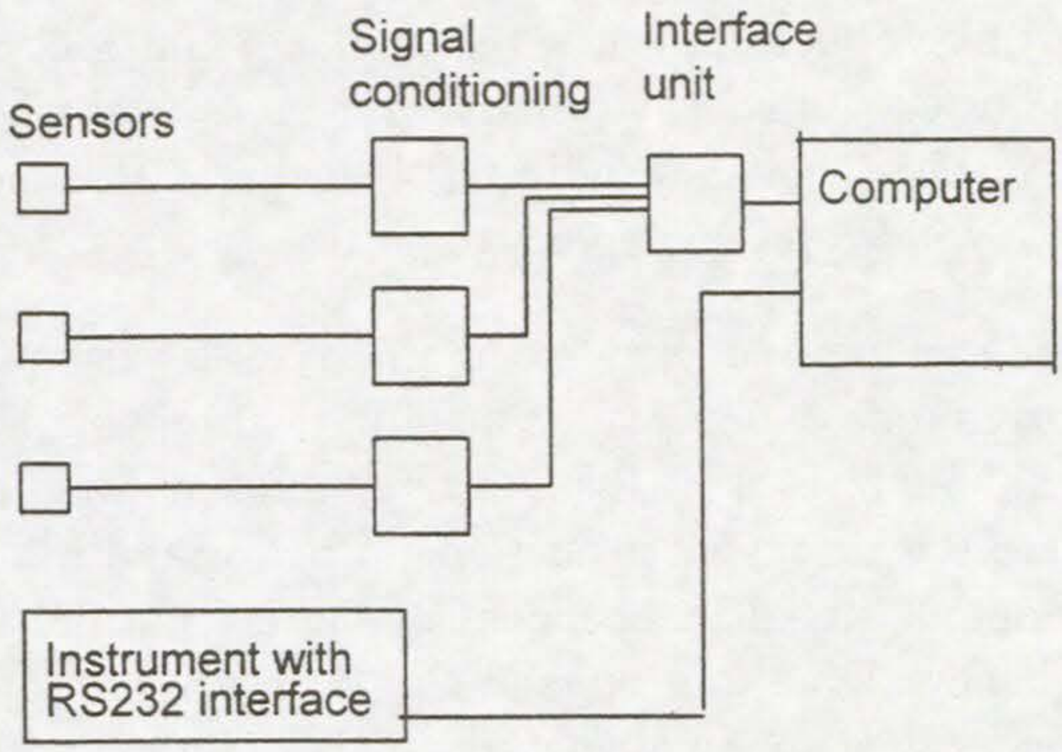


Figure 1 - Typical Instrumentation System

On the left hand side of Figure 1 are sensors, sometimes called transducers, which produce electric signals which vary with the quantities to be measured. For example, a load cell which is used to measure force by means of strain gauges produces a voltage (a few millivolts) which varies in proportion to the applied force.

To the right of the sensors in Figure 1 is signal conditioning circuitry which raises the signals from the sensors to levels, typically a volt or more, which are suitable for input to the interface unit. Signal conditioning is not required for those sensors which either produce suitable signals directly, or which include integral signal conditioning packaged with the sensor.

A general purpose computer does not contain all the electronics necessary for data acquisition and so an interface unit(s) is generally required between any signal conditioning and the computer. The only type of instrument which can be directly connected to a computer without some form of interface unit is an instrument which is designed to plug into one of the ports built into the computer, typically one of the serial ports which are fitted as standard to most computers. This is as shown at the bottom of Figure 1.

4. SOME BASIC CONCEPTS

4.1 Analogue Signals

An analogue signal is a variation in a parameter such as voltage, current or frequency, this variation signalling a corresponding variation in the magnitude of some measured quantity. For example, in yacht research, the measured quantity might be rudder angle. The rudder or the steering mechanism could be mechanically linked to a potentiometer, as further discussed in section 7.4 below, and this potentiometer could then produce a voltage which varies in proportion to the rudder angle. Measuring this voltage indicates the angle of the rudder, for example the system could be adjusted so that +5v (relative to a zero level which would normally be the ground or 'chassis' voltage) indicates 45 degrees to starboard, 0v indicates straight ahead and -5v indicates 45 degrees to port.

Varying current and varying frequency are alternatives to varying voltage as a means of indicating the magnitude of a measured quantity. Current signals can be converted to voltage signals simply be passing them through a resistor and buffering the output if necessary. Buffering is discussed in section 4.4 below and is a method for making the voltage of an output signal independent of the current drawn from the output. Converting a frequency signal to a voltage signal is a little more complicated than converting a current signal to a voltage signal. It requires a frequency to voltage converter circuit or possibly the software equivalent of such a circuit based on counting and timing functions.

An advantage of using current or frequency signals rather than voltage signals is that they are less affected by interference, otherwise known as 'pickup'. Interference occurs when the signal-carrying cables are located in regions of varying magnetic and/or electrostatic field with the result that these fields superimpose an unwanted signal on top of that which is intended to indicate the measured quantity. Fields which potentially could cause interference are present everywhere, but are particularly strong in the vicinity of inadequately shielded digital electronic equipment and electric motors. Interference can be a major problem with low level analogue voltage signals, for example the signals passing between a load cell and the associated signal conditioning, these signals being in the range of only a few millivolts. Once such signals have been amplified by signal conditioning they are usually raised to a level of at least a volt and are then much less susceptible to interference. The precautions which can be taken to protect low level analogue voltage signals from interference are discussed in Section 7.6.

There are commonly used ranges for analogue voltage and current signals in industrial instrument systems. Sensors which produce analogue current signals often use a 4mA current to represent the lower end of the measuring range and 20mA current for the upper end of the measuring range. Sensors which produce analogue voltage signals often use either 0 and 10 volts for the lower and upper limits (this being known as a unipolar range), or +5 and -5 volts (which is a bipolar range). If one needs to connect a 0 to 10v analogue signal to a computer interface unit which will only accept say, 0 to 5 volt range then a simple voltage divider can be arranged using a pair of resistors, see figure 2.

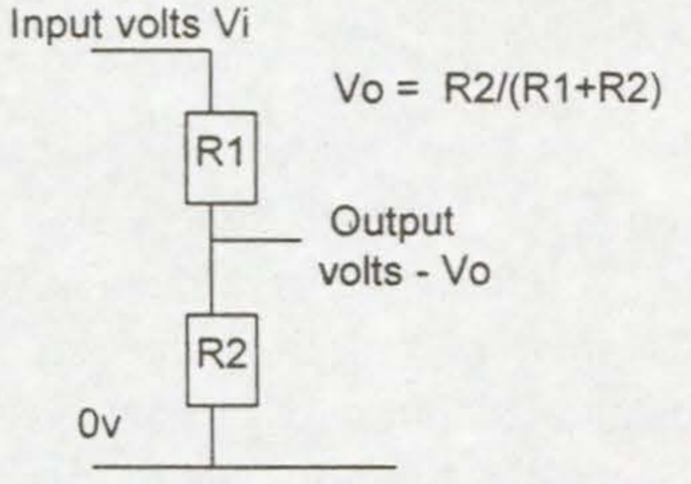


Figure 2 - Voltage Divider

The value of these resistors should be high enough that the current drawn from the sensor output is well within the rating for the sensor as specified by the supplier of the sensor. If the computer interface or other device connected to the output in Figure 2 is likely to draw anything other than a very small current then it is advisable to 'buffer' the output signal as discussed in section 4.4 below.

4.2 Digital Signals

Digital signals are an alternative to analogue signals as a means to electrically represent the magnitude of measured quantities. A digital signal transmits numbers which indicate the magnitude of a measured quantity. Virtually all practical systems use binary numbers which consist only of the digits '1' and '0', these two digits being represented as high and low voltage levels. In many systems, including those which carry the abbreviation 'TTL', high is a voltage of around 5v above ground and low is a voltage at or near ground voltage, i.e. the voltage of the metal frame of the equipment.

An example of a digital signal would be the output from an absolute optical angle encoder (one type of sensor used for angle measurement as discussed in Section 7.4 below). Such a sensor would be an alternative to a potentiometer for measuring the angle of a rudder. The cable connecting to an absolute optical encoder contains a number of separate cores or lines (i.e. wires) each of which can be energised to one of two voltage levels e.g. 0v and 5v. Suppose there are eight separate cores in the cable then reading the voltage on each core in turn and interpreting 0v as a 'zero' and 5v as a 'one' produces a binary number with 8 digits, that is 8 bits. This binary number would be in the range 00000000 to 11111111 – a decimal number range of 0 to 255. This number can be used to indicate the angle being read by the sensor with a precision of one part in 256, known as eight bit precision. Greater precision requires more cable cores.

If the full scale range of the encoder is 360 degrees the maximum error which can be attributed to the use of an 8 bit signal is plus or minus half of 360/256 degrees, that is +/- 0.703 degrees. If a twelve bit signal is used this maximum error would be reduced to +/- 0.044 degrees which is probably more than good enough for most applications in yacht research. The total error in the measurement may of course be much higher than the error due to digitising the signal since if the optical encoder is badly made mechanically it may be sending out the wrong numbers altogether, regardless of the number of bits in these numbers.

For practical reasons, the output from an optical angle encoder is sometimes in Gray code rather than in binary, but Gray code can easily be converted to binary by a computer program. For details of Gray code see AYRS publication 119.

The actual number of cores in a cable carrying an 8 bit parallel digital signal is generally at least 9 rather than 8, since a ground voltage core is almost always included and there may well be other lines to transfer power along the cable and also perhaps for control signals to indicate system status etc. It is quite common for 8 bit parallel signals to be carried on 25 core cable. This is often to allow standardisation of cable connectors which is more important than having a few unused cable cores. The parallel printer port found on most computers is an example, this having a standard design of 25 pin connector of which 8 pins carry the parallel data, 4 pins carry control signals from the computer to the printer and 5 pins carry control signals from the printer to the computer. The various control signals are used by the system for 'administrative' purposes, e.g. for the computer to tell the printer to get ready to start printing or for the printer to tell the computer to stop sending data because the paper has run out or jammed up.

Digital signals are generally more immune to interference than analogue signals. It would take a very large amount of interference to modify a voltage of 5v to such an extent that it could be mistaken for a ground level voltage or vice versa. Another advantage of digital signals is that they are transmitted as binary numbers which is the 'language' used by computers and so they can be directly processed by computers and other digital electronic hardware. For these reasons digital signals are now widely replacing analogue signals in telecommunications which, broadly speaking, is the largest field of application of electronics. However, analogue signals and circuits will never be completely eliminated since most sensors and other devices which interface electronics with the outside world use analogue signals, (an optical angle encoder is an exception in this respect) but it has become normal practice for analogue signals to be passed through an analogue to digital converter (ADC) to convert them to digital form for further processing.

4.3 Serial and Parallel Signals

The transmission of digital signals can be either parallel or serial. The optical encoder described above is an example of a parallel transmission, meaning that all eight bits in the signal are transmitted simultaneously using one wire for each bit.

Serial transmission means that the bits are transmitted one after the other on a single wire, although at least one other wire is usually needed to provide a ground reference voltage.

The rate of transmission of bits is expressed in bits per second. The standard size of binary number used in many systems is eight bits long, a group of eight bits being known as a byte. A commonly used rate is 9600 bit/s which means that each bit is transmitted in 104 microseconds. There may be one or more start/stop bits as separators between bytes and a further refinement is a parity bit following the end of each byte, this being used by the receiving equipment to check that each number has been correctly received. If it is required to send binary numbers of more than 8 bit length, say 16, 32 or 64 bits, then these would normally be transmitted as multiple bytes which are 'joined together' by the receiving equipment.

An example of a serial signal would be a signal conforming to RS232 specification, this specification being widely used for the signals transmitted between computers and their peripheral devices including mice, printers etc. but not for the high speed devices such as disc drives since RS232 would be too slow for such purposes. RS232 signals are also often used to send data between instruments and computers, for example the modern type of engineer's calliper gauge often provides an RS232 output so that a reading can be recorded by a computer each time the gauge is used to measure a part. Not only can the computer display the readings rather more clearly than is possible on the small LCD display on the instrument itself, but the computer can do all kinds of calculations, for example to check the dimensions against tolerances or even to show how the quality of work varies over the working week.

For industrial instrumentation systems, there has been a tendency in recent years to locate analogue to digital converters in close proximity to each sensor, or to build them into the sensors. This minimises interference since there is a minimum length of wiring carrying analogue signals and it also greatly reduces the quantity of cabling since digital signals from numerous sensors can be transmitted one after another along a common cable which interconnects all the sensors together with the computer(s) or other equipment which utilises signals from these sensors. Such a system requires some standardised method, or protocol, to attribute each signal to the correct sensor. Manufacturers of yachting instruments are now widely adopting this approach and calling it an 'integrated' instrument system. However, for the type of instrumentation discussed in this booklet, in which a computer acts as the 'hub' of the system, it is probably simpler to bring all the analogue signals back to an interface unit(s) which incorporates ADC and which is mounted close to (or within the case of) the computer. It is also likely to be convenient to mount the signal conditioning adjacent to the computer, so as to keep all the electronics in one location which can be suitably protected against the elements. The disadvantage is that cable runs from sensors back to a central computer may be quite long, increasing the possibility of interference on any low level voltage signals. A yacht under sail is not an electrically 'noisy' environment, so with luck there will be no problem. If there is a problem then it may be necessary to move the signal conditioning amplifiers for sensors such as load cells closer to the sensors.

4.4 Operational Amplifiers

Operational amplifiers, or op-amps, are electronic devices which feature in many simple analogue circuits used in signal conditioning for data acquisition. Brief details of these devices are thus included at this stage, rather than describing them separately for various application circuits. The circuit for the servo potentiometer connected to a unity gain buffer (see Figure 3 below) is a simple example of the use of an operational amplifier.

Physically, an op-amp in the form used in simple circuit construction is an integrated circuit (IC) contained in a dual in line (DIL) package. A DIL package is usually a small block of black plastic with metal 'legs' or pins which are soldered into a circuit board to make electrical connections to the circuit which is sealed inside the plastic. It is often convenient to have two op-amps within a single DIL package, this being called a dual op-amp IC. Quad op-amp ICs also exist. If it is required to use only one of the two op-amps within a dual op-amp IC it is advisable to ground the pins which connect to the unused op-amp.

An op-amp is often shown as a triangle in a circuit diagram (see figure 3). An op-amp has an inverting input (marked '-' in the figure 3), a non-inverting input (marked '+' in figure 3), an output (marked Vo in the diagram) and power supply connections, sometimes called power rails, which are shown connected above and below the triangle in figure 3 but which are often omitted from circuit diagrams altogether since it is known that they are needed for all op-amps and other ICs. The capacitor C3 connected across the power rails in close physical proximity to the op-

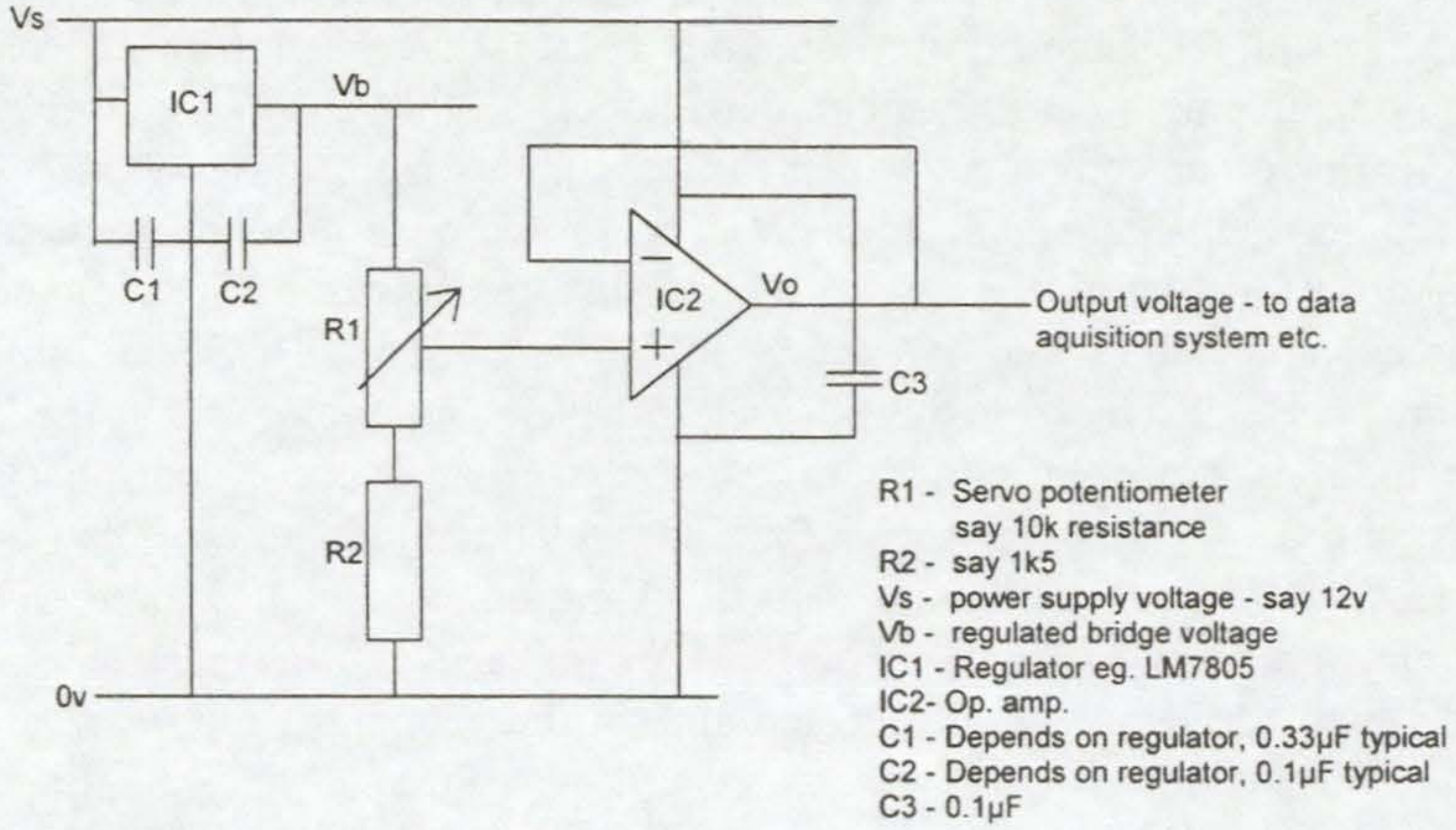


Figure 3 - Typical op-amp circuit

amp is good practice for most types of op-amps but may not be essential. When an op-amp is functioning in a circuit it attempts to produce an output voltage which is a very large multiple (i.e. a factor of tens of thousands or more) of the algebraic difference in voltage between the two inputs, but at the same time it cannot produce an output voltage which is above that of the positive supply rail or below that of the negative supply rail. In effect this means that any significant difference between the input voltages will cause the output to 'hit the rails' i.e. to jump to the voltage of one or other of the rails. It is only when the two inputs are at virtually equal voltage that the output voltage can be somewhere between the rail voltages and this is the situation which normally exists when an op-amp is functioning correctly in a circuit.

The circuit shown in figure 3 is a very simple example of the use of an op-amp. The steady voltage Vb is applied across a variable resistor and the optional fixed resistor R2. The voltage at the wiper of the potentiometer responds according to the mechanical position of the potentiometer wiper and this wiper voltage is taken to the non-inverting input of the op-amp. The inverting input is connected directly to the output of the op-amp. The op-amp responds to the difference between the non-inverting and inverting inputs and if the voltage of the non-inverting input rises even slightly above that of the inverting input the op-amp very rapidly increases its output voltage just enough to keep the two input voltages equal. This means that the output from the op-amp 'follows' that of the input from the potentiometer. An op-amp used in this way is known as a unity gain buffer.

One reason for using a unity gain buffer rather than simply using the wiper voltage as an output is that the voltage at the output of the unity gain buffer is independent of any small current which may need to be drawn from this output, provided that this current is within the current rating of the op-amp. A second reason is that very little current ever flows into the inputs of a properly functioning op-amp, and so the potentiometer wiper is not required to pass current. This is an advantage when using high precision potentiometers since these can be damaged by taking significant current through the wiper. As shown later, slight modifications to the circuit shown if figure 3 can produce an output signal voltage which is an amplified version of the input signal voltage, and/or can provide a level shift between the input and output voltage signals.

Note that if the inverting and non-inverting inputs to the op-amp in figure 3 were to be reversed the circuit would not function since any difference between these two input voltages would cause the op-amp to adjust its output voltage in such a direction as to increase rather than reduce the input voltage difference. The practical result would be that the output voltage would be permanently at one of the rail voltages. If in the process of fault finding this is found to be happening then one of the first points to check is that the op-amp inputs are connected the right way round!

The exact voltage used to energise the supply rails for a circuit based on op-amps is not critical. 12v is typical and a yacht's 12v DC power supply would normally be suitable. Op-amps will not function correctly if their output voltage gets too close to the voltage of either supply rail. With most types of op-amp it is best to keep the output voltage at least 1v clear of the supply rail voltages although with some types 0.5v is acceptable. In figure 3, adding the fixed resistor R2 in series with the potentiometer is suggested so that, even if the variable resistance of the servo potentiometer falls right down to zero, the voltage to the non-inverting op-amp input, which the output will follow, will still be a little above the 0v rail.

To match the signal conditioning output properly to the input range of a computer interface unit, it may be advantageous to be able to make the signal conditioning output vary right down to 0v or to vary both above and below the 0v level in the case of ADC circuits which use a bipolar range such as -5v to +5v. If we want to be agle to have 0v or negative voltage output from our Op-amps then we need an op-amp supply rail which is at negative voltage relative to ground. For this reason the power supplies for op-amp circuits often provide supply rails symmetrically above and below ground level, +12 & - 12 volts being typical. This allows the op-amp output voltages to vary above and below the 0v level without coming anywhere near to either power supply rail voltages and such a 'symmetrical' power supply arrangement may also give better performance for critical applications.

The disadvantage of positive and negative supply rails is that slightly more complicated power supply arrangements are needed, one cannot just connect the circuit to the 0v and +12v of a yacht's DC supply. If working from a 240v mains supply the easiest solution could be to buy a ready made power supply module which has supply terminals at typically -12v, 0v, +12v and perhaps also 5v, this later voltage being useful for powering digital circuits. Such modules are relatively inexpensive and they can also provide mains isolation for safety. If using batteries then either a second battery can be used with its +ve terminal connected to the 0v level, which is simple but a little bulky, or there are negative supply generator ICs which generate a low-power, negative supply rail voltage whilst only needing a positive one for their own power supply. For example, the ICL7660 IC works in conjunction with three externally connected capacitors to generate a -5v rail voltage for low power applications.

5. THE COMPUTER

The quality of the results obtained from data acquisition systems depend much more on the equipment connected to the computer than on the computer itself, and so a highly specified computer is not essential for most data acquisition work. Considering the popular PC range of computers, one with a 286 processor would be satisfactory, although a better computer is no disadvantage. Many AYRS members will already have a suitable computer, but if it is required to buy one to be used only for data acquisition then I am told that second hand 286 machines now change hands for £10 ($15) or so. Such a machine would also be suitable for general purpose use provided that one is prepared to use software of similar vintage to the machine and one is not contemplating using it for 3D modelling, finite element analysis or other work which is highly demanding on the computer hardware. If up to date software is thought to be essential, i.e. software based on modern operating systems such as 'Windows', then an old second hand computer will be inadequate and more money will need to be spent, at the time of writing this would be a minimum of just under £1000 ($1600) for a desktop model or somewhat more for a portable.

Some years ago I used a small petrol generator for powering an office style desktop computer out of doors but this was somewhat inconvenient. A car battery or yacht's 12v supply together with an inverter unit to change the 12v DC to 240v AC is cleaner and quieter than a generator but unless the 12v supply is capable of producing perhaps 10 or 20 amps for long periods it will only be suitable for short term use with a normal desktop computer.

IMPORTANT: If you use 240v power in a marine environment then due attention MUST be given to electrical safety. This applies regardless of whether the supply is from a generator, an inverter or from dockside mains power point. Handbooks on yacht electrical systems will give details of required isolation transformers etc.

For many of the experiments which might be of interest to AYRS members a portable computer would be more suitable than a desktop model. It does not depend on mains power, it is light and compact, and it is more easily made splash proof by enclosure in a plastic bag. Unfortunately, it takes an expensive portable computer to match the features and speed of even a moderately priced desktop model, and the displays on even the most expensive portable computers are still inferior to the best desktop displays, although they are certainly catching up fast. If you need to use a portable computer as your only computer it may be worth having a supplementary CRT display to use with it when portability is not needed. Another possibility could be a desktop computer for prolonged work supplemented with a budget priced portable, perhaps second hand, for data acquisition and other short periods of mobile use. If purchasing a portable computer for use on a yacht then it is likely to be worth choosing a model which can be recharged directly from the yacht's DC supply.

If it is required to have a computer for permanent installation aboard a yacht, rather than just for short term experiments, then weatherproof equipment would be necessary for any parts of the system which are used on deck or in the cockpit. Possibly even equipment installed below decks should have some degree of weatherproofing. At the time this booklet was drafted there was little computer hardware specifically designed for use on yachts. This situation has changed rather suddenly and at the 1997 Boat Show there were a number of computers which are designed either with outdoor use in mind or were specifically intended for use on board a yacht. I have included a list of these products in Section 11 but since this area is advancing rapidly this list could now be out of date.

With reference to section 11, some brief comments are as follows:

The Panasonic CF-25 ruggedised portable computer is a good quality portable computer with conventional layout but with a metal rather than plastic case and with shock absorbing mounts for the shock sensitive components such as the drives and the LCD display. The case and plugs are water resistant to the extent that the computer is claimed to be suitable for unprotected use in hard rainfall. Presumably it would need to be kept away from driving spray and dollops of green water. The Panasonic CF-25 offers similar capability to other good quality portable computers, i.e. Pentium processor, TFT display, and optional CD-ROM drive and sound card. The dimensions and styling are also similar to many other portable computers. The price is around £3,500, depending on exactly which optional extras are included.

The Fieldworks computers, models FW5000 and FW7600 follow a similar concept to the Panasonic CF-25 but are even more expensive (starting price £5,500) and perhaps slightly more rugged, they are certainly a bit larger and heavier. The FW7600 is particularly bulky for a portable computer but this larger size gives space to fit full size ISA expansion cards inside. There can be few if any other portable computers which offer this feature.

Aqualogic supply the Console PC computer which is intended for permanent or semi-permanent mounting on a yacht. It is likely that most purchasers will use it with chart plotting and other 'yacht management' software and so NMEA0183 compatibility is built in as standard - see Section 7.12 below. It is a sturdy metal box with a high quality colour LCD display on the front together with waterproof buttons which act as a mouse. It is provided with a bracket suitable for mounting at a chart table or in front of a cockpit steering position and it is powered by ship's supply, a range of voltages being acceptable. It is claimed to be resistant to heavy rain and spray but the salesman admitted that it might not survive full immersion. The same is probably true of most other computer equipment which is claimed to be weatherproofed for marine use. If you need truly waterproof equipment then look for an IP67 or IP68 specification - or make your own watertight box. The Console PC would normally be used with software which can be controlled by mouse or by the optional touch screen and so a keyboard is an optional extra. It is not intended to be an office machine but I see no reason why this computer, or others similar to it, should not be taken ashore, fitted with a keyboard and a mains adapter and placed on a desk for general purpose use. Although it is not designed to be a portable computer it is more portable than a typical desktop system.

The Fistar 3000, supplied by Fahrion Electronic GMBH follows the same concept as the Console PC but has a built in keyboard on the front rather than just mouse buttons. This built in keyboard is an arrangement of function keys and cursor control keys which would be suitable for controlling programs such as chart plotting programs, it is not an office style 'QWERTY' keyboard.

Wavelength Marine supply a marine computer system which includes 'docking stations' into which the system can be plugged to make an immediate connection to the power supply and remote sensors. The literature suggests that one docking station could be installed at the chart table and another on deck so that the computer could be available at both locations. This is of course also possible with other computers, if one is prepared to plug and unplug the various cable connections each time the computer is moved. At the time of writing I have not been able to obtain full details of the Wavelength Marine system but apart from the docking stations it would appear to be comparable to the Console PC and the price is similar. A special feature of the Wavelength Marine system is that, at considerable extra cost, it can be supplied with software and hardware which enable it to be a radar as well as a computer. This makes it possible to display a chart with the current GPS position marked and to superimpose a radar display centred on this position so that features indicated by radar can be immediately matched with charted features.

Softwave supply the Sea PC which is comparable in features to the Console PC but is waterproof on one side only. This means that it has a waterproof front panel with an LCD display and waterproof buttons which provide the function of a mouse, but the rest of the housing, including the various connectors, is not waterproof. To make a waterproof unit, the Sea PC is intended to be built into a watertight box supplied by the customer, or to be mounted through a bulkhead which will always be dry on one side. This would seem to be a good approach, and for experimental work the compartment behind the computer could be made large enough to house all associated signal conditioning, interface units, power supplies etc. The front panel part of the Sea PC is waterproof to IP67 rating, which means suitable for shallow immersion and so it should survive even a knockdown or roll over provided that the compartment behind it stays dry. NMEA0183 interfaces are available but are not included as standard. The Ocean PC, also from Softwave, is similar to the Sea PC except that the front panel has a waterproof key board as well as the display and mouse buttons. This is not a 'QWERTY' keyboard but an array of buttons, alphanumeric as well as function keys. Judging by the quoted specifications, the Ocean PC is not quite as waterproof as the Sea PC.

The computers intended specifically for marine use, – the Console PC, the Fistar 3000, the Wavelength PC and the Sea/Ocean PC – are all available with a touch sensitive screen, albeit at considerable extra cost. A touch sensitive screen allows the user to point to the screen with a finger rather than using a mouse to manipulate a cursor on the screen. Suitable software can set up a pattern of 'buttons' on the screen which can be selected by pointing at the screen to choose between options or to enter alphanumeric data, although a conventional 'QWERTY' keyboard would be preferred if a large amount of data needs to be typed in. Any software which can be used with a mouse can in principle be used with a touch sensitive screen, although software specially adapted for a touch sensitive screen is better since the human finger is not as accurate a pointer as is a mouse cursor. Chart plotting software in particular is now being developed to use touch screen control to best effect.

If you are planning to write your own software for use with a touch sensitive screen this would be similar to writing software for use with a mouse. If you are writing software for the Windows operating system then once you have got as far as understanding the complexities of the Windows system there it is little further complication in getting a mouse to work with your programs since the interface with the mouse is all part of the Windows system. If on the other hand you are writing non-Windows programs, which is arguably the easiest option for the beginner, then you would need to check with the supplier of the touch sensitive screen that there is interfacing software available to suit your preferred programming language.

For a fixed installation aboard a yacht it may be only the display and manual controls which really need to be weatherproof, since it would usually be feasible to install the rest of the system in a protected position below decks or in a purpose made fully watertight box. With this in mind Datalux, Aqualogic, Amplicon and Wavelength Marine all supply weatherproof LCD displays which conform to Super-VGA specifications and so could be used with almost any PC, either portable or desktop. All these displays are available at extra cost with a touch sensitive screen facility. The Amplicon waterproof displays (models MIM-106 and MIM-106T) are waterproof on one side only and so, like the Sea PC discussed above, they are intended to be built into a panel which will always be dry on the rear side. It is likely that in future the choice of waterproof computer displays will widen and possibly the prices may fall as solid state displays start to compete directly with CRT technology.

Unfortunately, the cost of computer hardware increases considerably as soon as requirements depart from those of the main market which is office and home users. Specialised equipment may also be harder to find second hand. The starting price for any of the full marine computer systems described above is around £3500, which is about three times the starting price of a conventional desktop system. The weatherproof displays which can be used with standard portable/desktop systems start at about £1100 for the display only, without the touch screen options. If you are working with a limited budget you may do better to buy a standard office/home computer, possibly second hand, then mount it on soft mounts within in a strong watertight box. Section 8 below includes a few suggestions for the construction of such a box.

6. THE INTERFACE UNIT

Computer interface units for data acquisition can take the form of unboxed circuit boards, referred to as interface cards, which are fitted inside the computer or they can be a separate box connected into the computer. There is another possibility which is known as a data logger. AYRS booklet No 119 discusses the use of a home built data logger in yacht research. A data logger is a unit which can operate independently of a computer while it is taking measurements from sensors and storing the results in some form of memory. In the old days (say 10 years ago!) data loggers were often expensive systems with keyboards and displays so that they could perform many of the functions of a computer in addition to taking readings from sensors. Nowadays a data logger is likely to be a plain looking box with no keyboard and either no display or just a small LCD type display. Such a unit is connected to a computer before taking readings so that software in the computer can be used to set it up. After taking readings it would again be connected to a computer so that the readings can be transferred from the memory in the data logger into the computer for processing, display and storage. This approach may be an advantage when it is required to take readings in an environment which is hostile to electronics and a small yacht could be a good example of such an environment. Only the data logger has to go on board the yacht, the computer system remaining back at base. The disadvantage is that there is little or no capability to examine the measurements while experiments are in progress and also the equipment tends to be expensive, perhaps because it is often built for heavy duty use in industrial process control. I think that a computer with a data acquisition interface is a cheaper and more flexible arrangement for most experimental work.

Interface units can be categorised by the functions which they provide and also by the method used to connect to the computer.

6.1 Interface Unit Connections

Card mounted within the computer casing.

An interface unit can be built in the form of an unboxed circuit board, or card, which plugs into a socket, or slot, on the 'motherboard' on which the main electronic system of a computer is assembled. The remainder of the data logging system is then connected to this internal card via a multi-pin plug(s) which is accessible from outside the computer casing once the interface card has been installed. This is the neatest arrangement with a desktop computer since there is no add-on box. However it can be a bit of a nuisance to keep having to dismantle the case of the computer to fit and remove internal cards, or to adjust the manual controls which are sometimes fitted on these cards. Internal cards are available with two types of connection to the computer circuits: ISA bus cards and PCI bus cards, although the latter are not suitable for older computers. Both types provide a very fast method of data transfer between the card and the computer but the PCI method is the fastest and the more recently introduced.

Plug in PCI and ISA cards are available to provide a computer with various add-on functions apart from data acquisition functions, for example sound output or a telephone connection to the Internet or even a built in GPS system. Also, some of the basic functions of a computer can also be provided by internal cards, for example the display control system of many modern computers is constructed in the form of a PCI card. An advantage of this approach is that if the customer wants to upgrade the display, say to provide enhanced moving displays of three dimensional objects, then only the display control card needs changing. For data acquisition, the speed of PCI cards is not usually necessary and so many data acquisition cards are ISA cards. National Instruments and Adept Scientific (see Section 11 below) supply a particularly wide range of PCI and ISA cards for data acquisition. ISA cards come in two sizes, full length and half length. Most modern desktop computers have internal slots to accommodate several PCI and ISA cards but it may be found that not all these slots are physically large enough for full length ISA cards.

Some of the internal cards for data acquisition include signal conditioning as well as the interface with the computer. This is a neat arrangement if you are sure of your requirements for signal conditioning at the time of buying the card. One might question whether signal conditioning circuits for low level analogue signals such as strain gauge signals should be within the electrically noisy environment inside the case of a computer and at least one manufacturer gives this as a reason for not supplying internal cards with signal conditioning for such applications.

The price of an internal data acquisition card obviously depends on the functions provided by the card, but few cost less than £100, and few cost more than £1000.

PCMCIA cards.

Most portable computers do not have physical space within their casing to accommodate ISA or PCI cards as described above, or if they do they probably only have space for a limited number of such cards and not for full length ISA cards. However, most modern portable computers can instead accommodate one or more PCMCIA cards which plug into a slot in the side of the case. PCMCIA cards are a thin flat box with a circuit board inside so they are reasonably robust either in or out of their host computer. Most of the functions which are available with PCI and ISA cards for desktop computers are now also available with the physically much smaller PCMCIA cards and the cost is generally similar. If you need to use a PCMCIA card with a desktop computer you will need an adapter.

Large external system, typically modular or rack mounted

Such a system would be a box, or rack, external to the computer, this rack probably accommodating a selection of plug in modules providing signal conditioning functions as well as computer interface functions. This type of modular system can be further extended in size by fitting a number of racks, typically of the 19" wide type, into a large floor standing cabinet, as may be necessary for data acquisition systems with perhaps hundreds of sensors. Typically there might be one module for each connected sensor, although sometimes modules handle groups of sensors. The connection between the rack and the computer would typically be a cable plugged into an internal ISA or PCI card fitted in the computer as described above. Alternatively an RS232 link might be used if speed of data transfer is not critical. This type of modular data acquisition system often includes sophisticated features and tends to be expensive. A system for just a few sensors is likely to cost over £1000 and large custom built systems can be very expensive.

External unit with RS232 or parallel port connection

This is the most likely to be the most appropriate for many amateur experiments. Various small external data acquisition units are available to connect into the RS232 (serial) or printer (parallel) ports which are found at the back of nearly all computers, desktop or portable. Some of these units are matchbox size and are built into a cable connector which plugs directly into the back of the computer. The features available are generally less sophisticated than with the options above, but these units are relatively inexpensive and have the great advantage that they can be readily swapped between computers, including both portables and desktops. Computer Instrumentation and Pico Technology (see Section 11), are two companies which supply this type of unit.

The units which work with the printer port usually offer a faster rate of data transfer than those which use a serial port(s). This use of the printer port for this purpose does stop you using your parallel printer at the same time as you are acquiring data but this will probably not be a great problem. If it is a problem then you may be able to use a printer which works, or which can be converted to work, with an RS232 port. I have often used the 'Minipod' printer port data acquisition units from Computer Instrumentation, for example the Minipod 100 which provides 8 channel 12 bit ADC for just under £100 including a bundle of software. Various other Minipods provide a wide range of alternative functions. I believe that this kind of unit could find many applications in amateur yacht research.

It is perhaps surprising how well these printer port interface units function, considering that the PC printer port is not really intended for input of data to the computer, being originally designed for data output to printers. To input data to a computer through the printer port it is necessary to rely on various control lines which are really intended for a printer to send occasional messages to the computer, for example to indicate when a paper jam has occurred. One possibility is to build your own interface unit from basic components and the book 'Easy PC Interfacing' by R A Penfold explains in simple terms how to build a printer port interface unit having one or two 8 bit analogue input channels or up to 16 single bit digital inputs, together with various output options. This is a rather limited number of channels and resolution compared to the most of the commercial products but it appears to be cheap and easy to build and so is probably a good option if you like soldering and have only modest data acquisition requirements.

A disadvantage of interface units which use the RS232 or printer ports is that the speed of taking readings has to be much less than the speeds which can be achieved with the fastest types of interface units which are more directly connected to the computer bus. Even so, it is possible to take thousands of readings per second using an interface to the parallel printer port and this should be adequate for many yacht research experiments. Serial port units do tend to be a bit slower and this could be a limitation. To take an example, suppose that a speed sailing craft is travelling at 50 knots (some hope) and is bouncing across wavelets which are spaced at 500 mm. If one wanted to study the stresses in the structure of this craft one might well like to record about 1000 sets of strain gauge measurements per second, so the number of individual measurements per second would be 1000 x no. of gauges. If just four strain gauge is required this is too fast for a serial port operating even at 56,000 bit/s but it should be within the capability of an interface unit connected to the printer port. If a number of strain gauges are to be read at this speed then this would probably require an interface unit which connects directly to the computer bus ie. a PCI or ISA internal card for a desk top computer (if the speed sailing craft can carry the weight!) or a PCMIA card for a portable computer.

6.2 Interface Unit Functions

Analogue to Digital Conversion (ADC)

Most data acquisition work requires ADC since as discussed in Section 4 above, most sensors produce analogue outputs whereas computers work with digital data.

Interface units with ADC usually offer a number of analogue channels, so that each channel can be connected to a separate sensor. Many experiments will require several sensors and needs tend to grow as experiments become more complicated so an 8 channel unit is likely to be a better choice than a single channel one. The next size up is 16 analogue inputs. If there are spare analogue input channels then it may be worthwhile using these channels to perform such functions as checking various steady voltage levels in the system for diagnostic purposes, e.g. to check bridge supply voltages or to warn when batteries need replacing.

The nominal output resolution of ADC systems is quoted in bits as discussed in Section 4.2 above and is typically 8, 12 or 16 bits. It is necessary to study the specifications to check the true voltage measuring accuracy as well as the nominal resolution. Ideally these should be comparable, although in the case of 16-bit units this is asking a lot, and lower accuracy is likely for all but the most expensive units. Accuracy of ADC systems and instrumentation in general tends to be quoted as a percentage of 'full scale' range. To avoid the risk of peak clipping, the signals will usually have to be adjusted to cover only part of this full scale range and so the accuracy considered as a percentage of the typical signal range will not be as good as the specified figures. For the type of work AYRS members are likely to have in mind, an 8-bit ADC will possibly be adequate, a 12-bit ADC will almost certainly be adequate and 16-bit units will be quite unnecessary. One would normally choose an interface unit and other signal processing circuitry which is at least as accurate as the connected sensors, but there is no point in paying for accuracy which is vastly better than that of the sensors.

Suppliers of interface units which include ADC often refer to differential inputs and single ended inputs.

A single ended input means that the analogue voltage signal for any one channel is input to the interface unit on a single line and the ADC circuit measures this voltage relative to a nominal ground level voltage which is often, but not necessarily, the chassis voltage of the equipment. Usually the interface unit will have a ground terminal (possibly referred to as 0v or analogue ground) and this will be connected to the ground terminal of the sensor or any signal conditioning so as to ensure that the voltage signal is both generated and measured relative to the same ground level voltage, ignoring of course the small voltage differences which can unfortunately occur between the two ends of a ground line. If a system of this type fails to function and the measurement of analogue voltage appears to fluctuating wildly then one point to check is that both ends of the ground line have actually been connected. ADC interface units often have a number of analogue ground connection terminals for ease of connection of ground lines for a number of separate measurement channels.

A differential input means that the analogue voltage signal is input to the interface unit on two lines and the voltage which is measured and passed to the computer in digital form is the difference in voltage between these two input lines. It is possible to connect one of the differential input lines to a signal and the other to a ground terminal on the sensor or signal conditioning but it is also possible to connect a signal to each line and measure the difference between these signals. One could for example have one differential input at 2v and the other at 3v, both relative to a nominal ground level. In this case the digital output from the interface unit would indicate either +1v or -1v depending on which way round the input lines are connected. With a single ended input, errors can be caused by small voltage differences between the two ends of a ground line as can result from pick up or because for some reason the ground line is carrying significant current. Such effects can be reduced by using differential inputs. If the two differential input lines are physically kept in close proximity, for example by use of a twisted pair cable, then any pickup will tend to affect both lines equally and will not affect the measured difference in voltage between the lines. The extent to which a system such as an ADC interface unit or an amplifier is immune to the effect of voltage fluctuation applied equally to two differential inputs is referred to as common mode rejection.

A differential input will normally use the same circuitry as two single ended inputs. For example, most 16 channel ADC interface units can be configured for either 16 single ended inputs or 8 differential inputs. Single ended inputs allow more sensors to be connected and should be satisfactory for most measurements discussed in this booklet.

One of the main specification parameters for interface units with ADC is the sampling rate, i.e. the frequency with which an analogue signal can be measured. Faster measurement requires faster and more expensive ADC circuits for making the measurements, although, as discussed above, the connection between the interface unit and the computer can also be the critical bottleneck. The really fast ADC systems, which are not necessary for most yacht research work, do not normally take readings continuously because the computer and the connection to the computer could not handle the flow of data. Instead the readings are taken in bursts and stored in the interface unit before being transferred rather more slowly to the computer.

Digital Input/Output (DIO)

This allows the computer to receive and transmit digital signals through a data acquisition interface unit, often in combination with various other functions provided by the same interface unit. Computers receive and transmit digital signals all the time, from the keyboard for example, but interface units which provide digital input and output are intended to provide a robust and easy to use connection between a computer and various external sensors and indicating devices. For example, single bit signals, ie. on/off signals, can be read from remote manually operated switches, proximity switches, liquid level switches and multi-bit parallel data can be received from sensors such as optical encoders. Digital output can be used to switch on and off devices such as remote indicating lights or solenoid valves in a fluid power system. It is an advantage for such applications if the interface unit is designed so that no damage can be caused if the digital IO channels are short circuited, or are accidentally connected to higher than normal voltages. Good quality interface units sometimes use opto-isolators to achieve this. Where digital output channels are required to deliver relatively high currents, say to operate a solenoid or to switch a lamp on or off, then power amplification will be needed in the form of electromagnetic relays, or electronic power switching (solid state relays). Some computer interface units do have switching or relays built in for this kind of application.

A possible yacht research application for an interface unit with digital IO channels would be to provide a small control box on deck which controls a computer installed down below. Such a control box could have a few waterproof buttons and LED indicating lights and could say, switch between different modes of data logging and inform the operator when a set of readings is complete. If the computer parallel port is free, then a simple way to provide a few digital IO channels for this kind or use is to wire into this port.

Timing and counting functions

Many of the more expensive interface units for data acquisition include these functions together with ADC, DAC etc. Other interface units are dedicated to these functions only. The usual approach is to generate one or more 'clock' signals which are series of pulses at accurately known frequency, like a ticking clock but probably much faster. One or more counter circuits are also provided and these can be used either to count the pulses from the clock to carry out a timing function, or to count the number of times that some external event occurs. A typical use for timing and counting capability on an interface unit is to synchronise an ADC function to ensure that an analogue voltage is sampled, i.e. measured, at accurately known time intervals and perhaps to synchronise these measurements with some external event. Fortunately, for many purposes it is not essential to know the exact times at which measurements are taken and it is then satisfactory to simply let the system take readings as fast as it can, avoiding the considerable complication of timing the measurements.

Digital to Analogue Conversion (DAC)

This is the opposite to ADC and it allows the computer to output analogue signals according to numbers which are generated by calculations performed by a computer program. I think that this is unlikely to be required for most applications in yacht research although it could be the basis of a sophisticated autopilot system which would operate under control of the computer. For example, ADC channels could read a range of parameters such as wind speed and direction, water speed, angle of heel and actual helm position and the computer could use this information to calculate the required helm correction as a number which represents an angular movement. The interface unit could then use a DAC channel to produce an analogue voltage signal according to this numerical data. This analogue signal could then be amplified by power electronics to drive an electric steering motor or to operate hydraulic steering control valves.

7. SENSORS AND SIGNAL CONDITIONING.

A large part of this booklet discusses sensors and signal conditioning since the accuracy and versatility of an instrumentation system is often more dependant on these components than on any others.

The various types of sensors and associated signal conditioning which are most likely to be of use in yacht research are discussed as follows:

7.1 Fluid Velocity Measurement in general - including air and water.

The measurement of the velocity of fluid flow allows boat speed and wind speed to be determined and may also be relevant to the detailed study of fluid flow around sails, hulls and hydrofoils. There are a number of approaches to the measurement of fluid flow including the following:

Mechanical turbines with means to measure rotation speed e.g. Propellers, paddle wheels etc. Measurement of the rotation speed is often by timing pulses produced as the turbine rotates. These sensors are widely used for boat speed and wind speed measurement and are further discussed under sections 7.2 and 7.3 below.

Positive displacement meters, e.g. the old type of gas meter or a petrol pump meter. These are potentially accurate but are only applicable to fluids flowing in pipe systems and so are probably not very relevant to yacht research.

Timing the filling or emptying of a container of known volume. This can be highly accurate but it is not very suitable for large continuous fluid flows and so is probably not relevant to yacht research, unless perhaps you want to measure fuel flow to determine the efficiency of an auxiliary engine. I have seen this done by installing a valve(s) so that the engine can be made to draw fuel from a small calibrated reservoir which has high and low level liquid sensors. A tall narrow reservoir would be best, or one shaped like a chemist's measuring pipette. After the flow measurement is completed the fuel supply must be switched back to the normal tank to avoid drawing air into the system and a computer controlled system can do this automatically using a small solenoid valve(s). There are various liquid level switches which should be suitable, e.g. Radiospares cat. No. 317-803 and such sensors could also be used to provide a low level warning for a yacht's fuel or water tanks.

Methods based on pressure measurements, for example the pitot tube which is still widely used in aviation. A pitot tube compares the pressure in the flowing fluid with that at a stagnation point, which is a point where the flow has been brought to a standstill by meeting an obstruction in the flow. According to Bernouli's theorem, the pressure build up at such a stagnation point is proportional to the square of the fluid flow velocity and so the velocity can be determined by pressure measurement. The fluid density needs to be known and for so for air speed measurement the readings need to be corrected for air temperature and pressure. In a laboratory situation the pressure measurement would typically be by means of a manometer which balances the pressure of one fluid against the pressure produced by a column of another fluid of different density. This can give accurate measurements as are used in wind tunnel work and in calibrating other types of flow measuring instruments. A laboratory style manometer is not practical aboard an aircraft, or sea going boat, and so pitot tubes on aircraft are used with electronic pressure measuring systems. Some people have made simple water speed pitot tubes consisting of just a transparent tube dipped in the water alongside a boat and having a bend facing forward at the immersed end. The stagnation pressure at the immersed end drives water up the tube and measurement of the height of the water column above the surface of the sea gives the speed of flow. I imagine that a limitation of this type of speed meter is that it is unlikely to be useable in rough water.

There is also a type of hand held wind speed meter which could be considered to be a form of pitot tube. This is a tapered cylinder with an orifice which is held facing into the wind. The air in front of the orifice is brought almost to zero velocity by the presence of the cylinder and the resulting pressure rise drives air through the orifice. The air flow through the orifice lifts a light disc up the cylinder and because the cylinder is tapered the leakage around the edge of the disc increases as the disc rises and so the disc comes to rest at a height which indicates wind speed. I doubt whether this type of instrument is as accurate as those instruments which use a wind turbine but it is slightly cheaper.

Timing the propagation of sound. It takes longer to row a boat between two points with an adverse current than with a favourable current. In the same way it takes longer for a pressure wave, i.e. a sound wave, to travel between a loudspeaker and a microphone if there is an adverse fluid flow velocity. There is a new type of domestic gas meter which works on this principle. Sound pulses are both transmitted and received by small piezo devices mounted at two locations along a tube carrying the gas flow. The pulses take longer to travel upstream than downstream and knowing the speed of sound in the gas the gas velocity can be determined by timing the departure and arrival of the pulses. This method is rather more accurate than traditional gas meters and it is also a potentially reliable since there are no vulnerable parts projecting into the flow and no moving parts unless one counts the piezo acoustic devices as moving parts. The method has been used for boat speed measurement although I think that some of the early instruments had problems. I would predict that in future this method will be more widely used both for boat and wind speed. If three or more piezo devices are mounted in an array there would seem to be a possibility of measuring flow direction as well as speed.

Tracking suspended particles or other flow markers. Most fluid flows carry small particles of suspended matter, or bubbles in the case of liquids. There are methods for measuring flow velocity by tracking these particles with ultrasonic sound or laser light. Sparks can be used to generate small regions of high temperature gas and these can be tracked by optical methods. Flow in the oceans is tracked with floating beacons and in the atmosphere with balloons. The Georgia Institute of Technology is developing a laser anemometer which tracks pockets of turbulence in the air to determine the mean wind speed across an extended sight line. The Defence Research Agency at Malvern has developed a laser 'radar' which uses a laser to track dust particles in the airstream around an aircraft and uses doppler shift measurement to map the flow pattern in the turbulent wake. Individual aircraft types can be identified from the turbulence patterns.

Cooling effect of fluid flow. The flow of fluid past an electrically heated filament will cool the filament and so change its resistance. The speed of flow can thus be determined by measuring the filament voltage and current. It is necessary to correct the readings to allow for fluid temperature which can also be measured electronically. Air flow meters based on this principle are known as hot wire anemometers. Hot wire anemometers are available commercially but are not the most accurate or cost effective solution for the measurement of averaged wind speed, rotating cup anemometers being cheaper and probably more accurate for this type of application. The advantage of hot wire anemometers over most other methods of flow measurement is that by using a fine filament the instrument can follow rapid velocity fluctuations and also the readings can be localised to a small region around the filament. This makes the technique appropriate for the study of turbulence and for measuring the thickness of boundary layers. There may be scope for the use of such methods in the detailed study of sailing boat rigs but there are likely to be difficulties in using hot wire anemometers in extreme conditions when the air flow is mixed with salt water.

Measurement of Coriolis force on a vibrating pipe bend which is carrying fluid flow. This is becoming popular since it offers the advantage that there is nothing at all projecting into the pipe. The method is inherently suitable only for flow in pipes.

7.2 Boat Speed Measurement

Boat speed is usually determined by measuring the speed of the water relative to the boat using an 'off the shelf' electronic instrument (marine speedometer) which gives a virtually instantaneous boat speed reading together with a mileage counter which in marine applications is called a log. It is also possible to determine boat speed by timing the passage of the boat relative to a land based or satellite based reference frame. This does not give an instantaneous reading but it is potentially more accurate than water speed measurements and is the only method acceptable for establishing sailing speed records. It is also a good method for calibrating instruments based on water speed measurement.

For many years AYRS has been at the centre of developments in the measurement of boat speed for the purpose of establishing speed sailing records. I will not go into too much detail since the history of these developments and the possibilities for future improvement could merit a separate AYRS publication.

Briefly, most measurements for speed sailing records are made by timing the passage of craft between sight lines set up with markers on shore or on securely anchored marker buoys. Accurate surveying of the sight lines is necessary, which can entail the hire of fairly expensive equipment. The distance between the start and finish lines is nominally 500 metres but does not have to be exactly 500 metres since a measured distance is used in the speed calculation.

In recent years AYRS has used a 'laser tape' to determine the distance between the sight lines. This instrument transmits a pulse of laser light which is reflected back from a distant target. Incredibly accurate electronic timing of the transmission and the receipt of the light pulse gives the distance. There are a number of instruments based on either this principle or on a slightly different principle by which the light amplitude is modulated and the phase angle of the transmitted and received light is compared. The particular instrument used by AYRS is a robust instrument suitable for use on a small boat. It has the advantage that it works with a not particularly reflective target such as the hull of Ian Hannay's yacht. Other instruments may be more accurate but require a special glass reflector (retro-reflector) to be attached to the target and the beam to be accurately aimed at this reflector, which would not be easy when working afloat.

Having established the distance between sight lines, which are hopefully parallel, the second problem is to time the craft as they cross these lines. This problem is complicated by the number of craft which may be crossing the sight lines almost simultaneously. At an event like Weymouth speed week it is inevitable that there will be little sailing for much of the time, then when conditions happen to be just right the competitors will all want to 'go for it'. In the early days, timing was by stopwatch. In the 70's financial support from Johnny Walker Whisky allowed the use of pairs of synchronised video cameras with time marked frames, these being lined up along the sight lines and housed in small sheds. This is still perhaps the most certain method, but it takes time manually searching the video footage. Computer optical character recognition to automatically identify the sail numbers from the video frames is an attractive possibility but there are likely to be problems when the sails are flapping in the wind or are aligned too close to the line of sight.

Now that funding is more limited, AYRS no longer uses video cameras and instead has developed a system by which human operators at each sight line use portable radios to send voice messages to a single computer operator to indicate when craft cross the lines and the identity of the craft. This system has mainly been developed by Bob Downhill. An improved system, which has been little used to date and which is mainly the work of AYRS members George Chapman & his son Joddy, provides the operators on the sight lines with buttons to press to mark the moments at which craft cross the sight lines and to simultaneously record wind speed. These buttons control the transmission of radio messages to the central computer. The moment of crossing the line is still estimated by a human being and there can still be problems when the course is busy.

The latest development, which is mainly the work of AYRS member Bob Spagnoletti, is to align infra red beams along the sight lines and to equip each competing craft with a small box which detects when it crosses each of the beams and at these moments sends a coded radio message to a central computer, these messages identifying the craft as well as being used for timing. At last we have the prospect of a fully automatic system but will it be practical, reliable and accurate? I certainly hope so.

Satellite Speed Measurement. Can GPS be used for measuring sailing speed records? For a 500m course probably not. Although differential mode GPS may be accurate enough in position finding (cm accuracy is possible with the most expensive systems) it takes time for the system to acquire these accurate readings leading to uncertainty in speed estimation. Differential mode GPS might however be considered for surveying sight lines, if AYRS could afford it. For long distance records, e.g. the 24 hour sailing speed record, GPS is fine even without differential mode and so GPS has replaced the use of astro navigation for this purpose. Incidentally, the 24 hour sailing speed record may now make sailing the fastest of all practical long distance transport methods (ignoring those methods which are doomed by being dependant on fossil fuels and other non-renewable resources!).

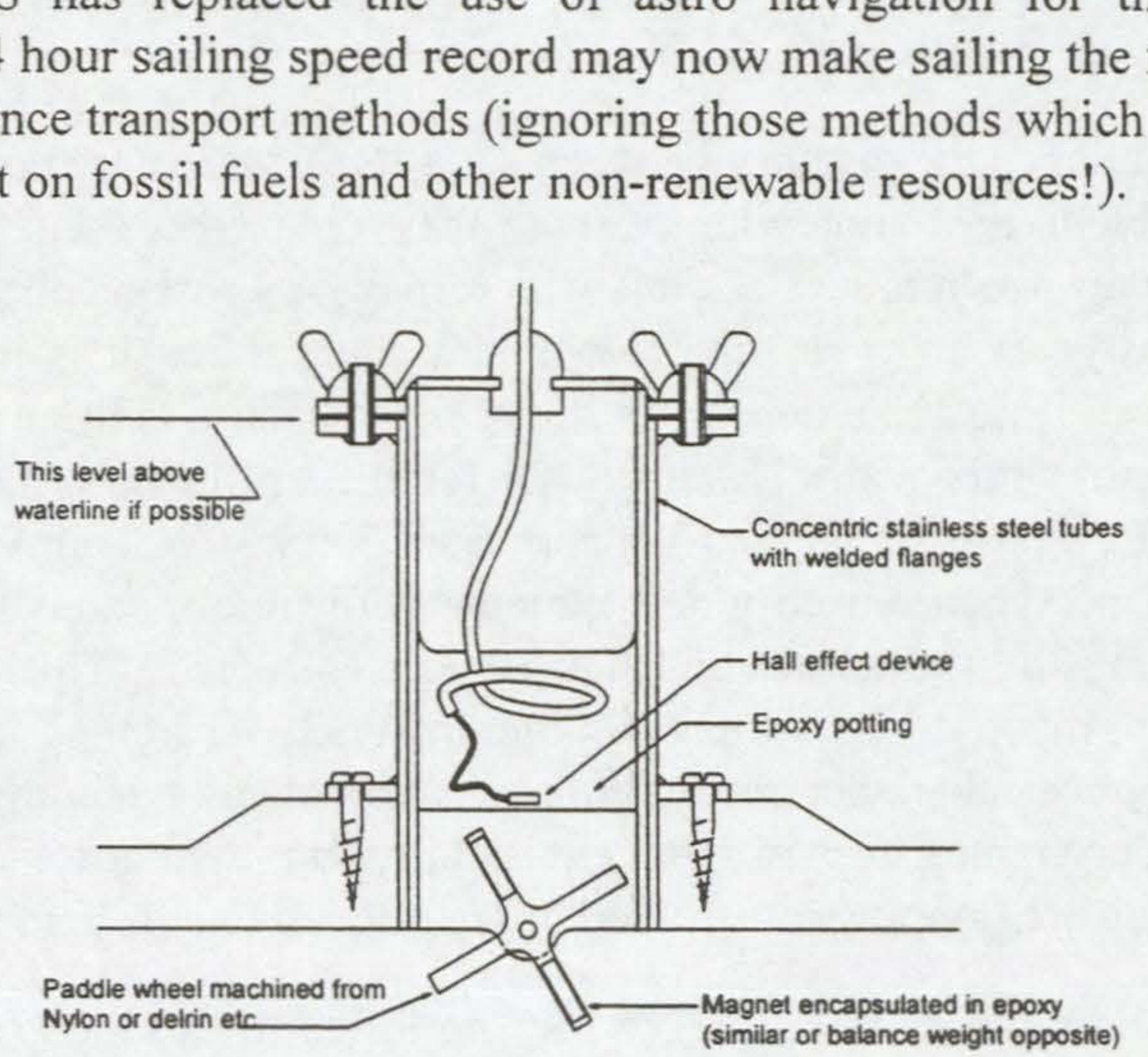


Figure 4 - Paddle wheel speed sensor

Boat Speed = Water Speed. We now return to using water speed measurement to determine boat speed, this being the usual method other than for speed record attempts and for instrument calibrations. The most usual water speed sensor for boat speed measurement is a small paddle wheel or a coarse pitch axial flow 'turbine' which spins under the influence of the flow. The spinning motion is usually used to generate electrical pulses the frequency of which indicates water speed. Amateur construction of this type of boat speed sensor would probably require machined parts and I suspect that it might be tricky to construct a unit which would match the reliability of the ready made ones, but Figure 4 may provide ideas for any one who wants to try. The paddle wheel could be milled to a cruciform section then turned spherical in the 4-jaw chuck so that it fits fairly closely into the end of the inner mounting tube. If there is space inside the boat, the whole assembly could be made high enough to project above the waterline so that the working parts could be withdrawn for cleaning or weed removal without much water getting into the boat.

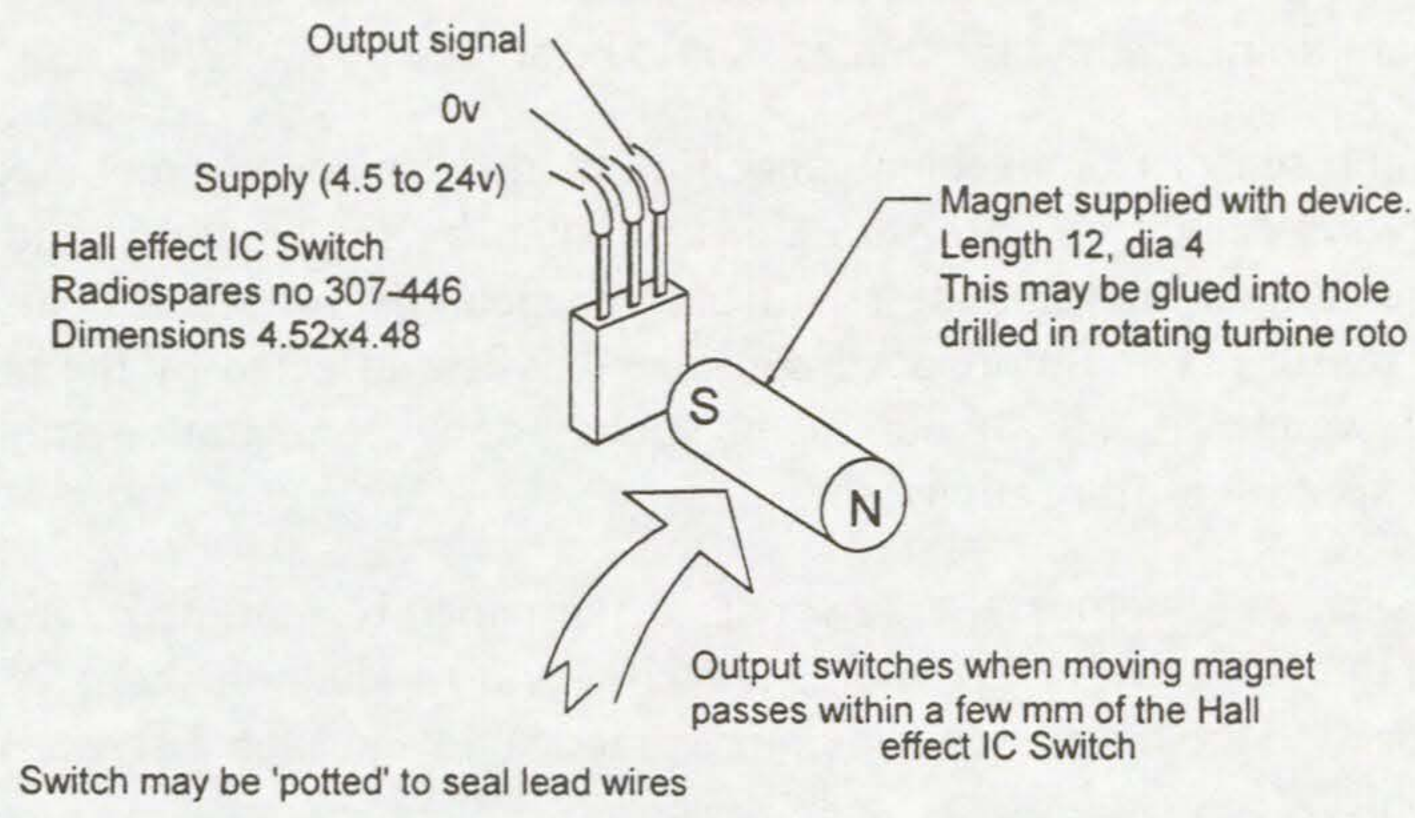


Figure 5 - Hall Effect switch

There are quite a few methods which could be considered to produce electrical pulses from a turbine flow sensor, for example a magnet passing a small coil to produce a voltage pulse, a magnet passing a reed switch, a magnet passing a Hall effect switch and optical methods such as an opaque vane passing between a light source (possibly infra red) and a photo electric detector. The Hall effect integrated circuit switch shown in Figure 5 above would be my choice since it is a cheap and compact method with no moving parts. It produces clean pulses which are of constant amplitude regardless of the speed of movement of the magnet. A 1 kOhm resistor (not shown in the diagram) should be connected between the supply and the signal line. If space in the sensing head is limited this resistor could be remote from the hall effect IC switch. The Hall Effect IC switch and its leads can be encapsulated in a potting compound to produce a waterproof robust assembly.

Ready made paddle wheel and axial turbine type sensors are available as spare parts for commercially produced instrumentation, e.g. the 'Autonic' speed sensors as discussed in AYRS publication number 119. This publication also describes the construction of a clever fully featured marine speedometer/log using an Autonic sensor together with an inexpensive speedometer readout as sold for pedal cycles. This readout would of course be superfluous if a computer is being used for data acquisition and display.

Paddle wheel water speed sensors are mounted on the under surface of a hull whereas axial turbine boat speed sensors can either be in this postion or can be towed behind on a length of cable. For a given rotor diameter and boat speed the axial turbine will probably be capable of more torque than the paddle wheel and it may also be more freely spinning since half the paddle wheel must tend to act as a water brake. One might thus expect the axial turbine to function at lower boat speeds and to be marginally more accurate. However both types work pretty well and the paddle wheel type is now much the most frequently used for under hull mounting, probably because it is slightly less likely to snag weed etc. It has been suggested that for the axial turbine method the blades should be angled about 50 degrees.

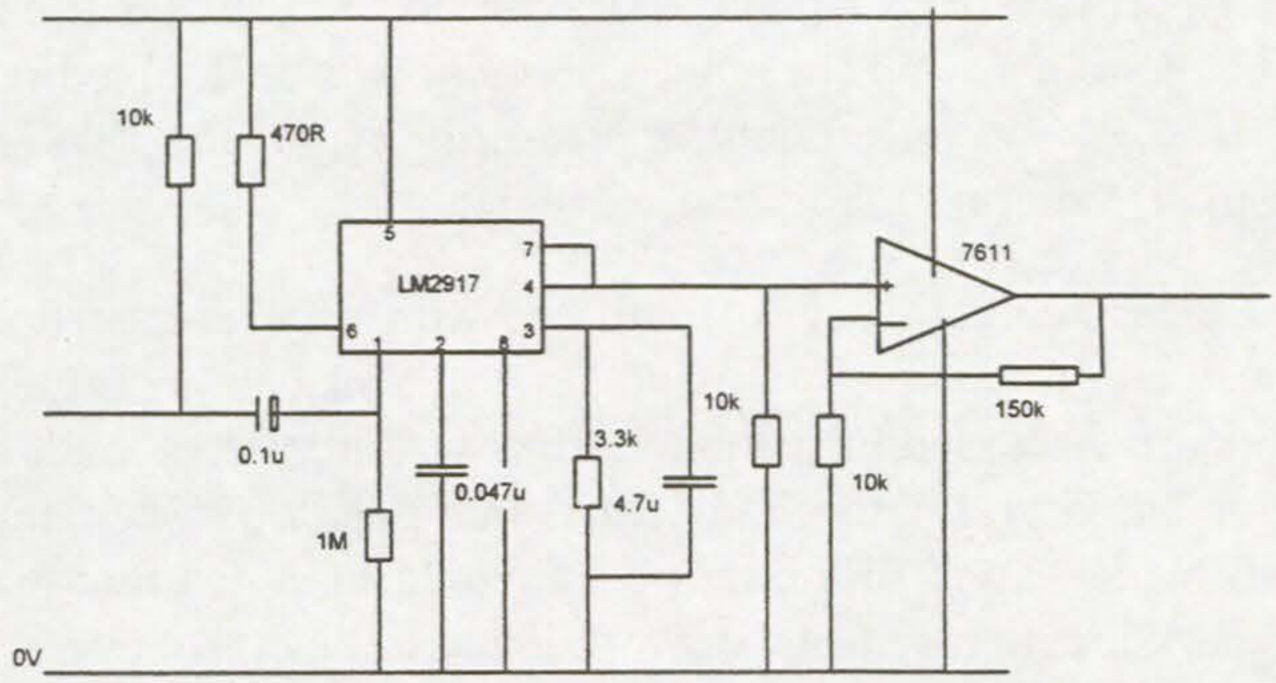
An under-hull sensor is convenient since it remains permanently mounted. A towed sensor may get caught up on obstructions or eaten by sea creatures and the towed cable causes drag which may be significant, particularly for small boats. However the towed sensor may be more accurate since it is less affected by the proximity of the hull. I wonder if any of our members has done comparative trials of these alternative speed sensor locations.

For craft such as dinghies and rowboats a permanently mounted sensor may be vulnerable to damage when the boat is launched and handled on shore. A removable sensor clipped to the transom may be more practicable and such a sensor is available from Autonic.

There are obvious difficulties in using hull mounted sensors with hydrofoil craft and with hulls which are expected to bounce clear of the water. Perhaps the system could be arranged to take readings only when the water pressure under the hull exceeds a set value. Small plastic pressure switches are available and might be suitable.

Counting Pulses

Having produced a stream of electrical pulses from a water or air speed sensor how do we determine the frequency of this pulse stream and get this information into a computer? As discussed above, there are interface units which have timing and counting hardware which can measure the frequency of incoming pulse streams and pass the results as binary code to the computer, but this facility is not available with the lowest cost interface units. Another method is to arrange for the computer itself to do the necessary pulse counting and timing to work out the frequency and hence the flow speed. This may cause difficulties if the computer is being expected to do other jobs at the same time, since it will probably be spending most of the time 'watching' its internal computer clock. A third alternative is to build an electronic circuit which converts the sensor pulses into a voltage which is then connected to an ADC channel on the interface card. This is a rather roundabout method but in some ways the easiest to implement.



LM2917 - Tachometer Integrated Circuit - Radiospares Cat. No. 302-047   Data Sheet 232-2582

Figure 6 - Frequency to Voltage Converter

Figure 6 shows a simple frequency to voltage converter circuit which is suitable for measuring the low frequency (by electronics standards) pulses produced by a turbine type of water or air speed sensor. All the circuits included with this article are very simple electronics and can be built by a non-electronics engineer, such as myself, using techniques discussed in section 8 below.

7.3 Wind Speed and Direction Measurement

Wind speed measurement in yacht research is usually by means similar to water speed measurement as discussed above, except that the familiar vertical axis rotating cup arrangement (the Robinson cup anemometer) is often used since it has the advantage of not needing to be aligned with the direction of flow. This type of air speed sensor is easier for amateur construction than is a water speed sensor, the parts being larger and less fiddly to assemble and it is not necessary to achieve a water tight seal through the hull skin. The rotation can generate electrical pulses using a device such as the Hall effect IC switch described in section 7.2 above.

It is always a good idea to keep in mind a realistic estimate of the accuracy of the various sensors used in an experiment. To give an idea of the accuracy which is achievable with a rotating cup anemometer, a manufacturer of very high quality anemometers of this type, such as might be used by the meteorological office or at airports, quotes the following figures:

Wind speed less than 1 knot:	No useful readings obtainable
Wind speed 1 knot to 20 knots:	Accuracy +/- 0.2 knots

Wind speed 20 knots to 150 knots: Accuracy +/- 1% of reading

It is reasonable to assume that home made equipment will not improve on this specification and indeed is quite likely to be much worse than this specification. It should also be noted that percentage accuracy falls significantly at low wind speeds and yet much sailing is done in drifting conditions. To determine the lift and drag coefficients of sails it is necessary to divide measured forces by the square of the wind speed. Because it is the square of the wind speed which is used, any percentage error attributable to the wind speed measurement will be doubled in its effect on the coefficient, ie. a +/- 1% uncertainty in measuring wind speed will lead to a +/- 2% uncertainty in determining lift or drag coefficient.

Wind speed measurement is often combined with measurement of the direction of the apparent wind as sensed by a wind vane attached to an angle sensor. Suitable angle sensors are discussed in section 7.4 below. Alternative methods, such as solid state methods based on the timing of ultrasonic pulses between an array of sensors may be more widely used in the future. It should be noted that masthead mounted wind speed and direction sensors are both likely to be quite severely affected by the heel of a yacht and the effect which the sails have on airflow local to these sensors. Mast twist may also considerably affect wind direction as sensed using masthead mounted instruments and one possibility to take this into account might be to mount a fluxgate sensor (see section 7.8 below) at the masthead so that the direction of the earth's magnetic field can be used as a reference for wind direction. The effect of angle of heel could perhaps be compensated in software using a measurement of heel angle, but this is rarely done even in expensive yacht instrument systems.

The effect of nearby sails seems likely to be difficult to correct in the software. Mark Chisnell, in his book on yachting instruments [1] states that masthead mounted instruments typically over estimate apparent wind speed by 15% when a yacht is running before the wind. If one were using such readings to determine the drag coefficient of a downwind rig, the result would be in error by approximately double this amount. There is no certainty that this error will be consistent between different rig designs so comparative measurements may well be rendered useless. Hence, although masthead mounted wind instruments may serve as a guide for the helmsman they may be of little value for rig development and other yacht research. Research workers at Southampton University and elsewhere have used wind instruments mounted on a spar extending from the bow of a yacht. It might make a project to find out how long and high such a spar needs to be and how well it works on different courses. Presumably for downwind work it needs to be stern mounted. Another approach to keeping wind instruments clear of the sails would be to mount them on a power boat motoring adjacent to the yacht under investigation, probably using radio telemetry to transfer data to a computer on the yacht. This could lead to another interesting project mapping the 'wind shadow' around a sailing craft.

7.4 Angle and Tilt Measurement

As discussed in section 7.3 above, the angle of the apparent wind direction is one angle which is obviously of interest in yacht research. Other angles which might be of interest are angle of heel, angle of a rotatable mast, angle of the boom to hull centreline and to the mast, angle of the rudder, angular adjustment of lifting hydrofoils etc.

A rotary potentiometer, or 'pot' is a simple method for sensing angles. The volume control knob on a radio is an example, turning the knob varies the potentiometer resistance and can produce a voltage change. For wind direction the potentiometer is connected to a wind vane, for angle of heel to a pendulum and so on. Special potentiometers, known as servo pots, are made for angle sensing and these are more accurate than the cheaper types used for volume knobs on radios. Servo pots cost from about £20. A point to check is the friction in the servo pot. This is of no consequence for measuring, say, rudder angle but it is important to have minimum friction for measuring the angle of a wind vane in light winds.

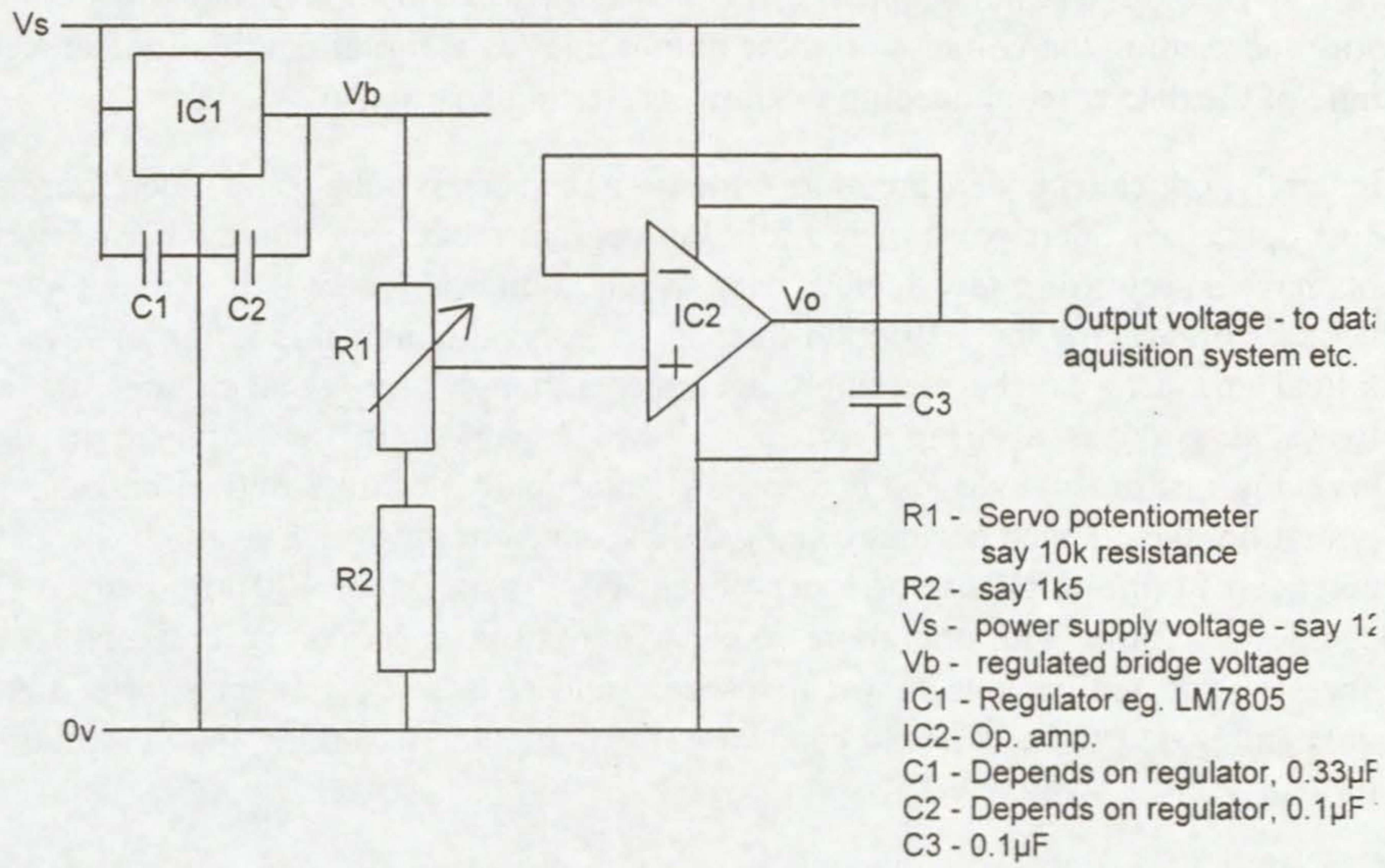


Figure 7 - Servo Pot Circuit

Most servo pots need to be operated with very low current at the variable voltage terminal which is known as the 'wiper'. If this current is not kept small (typically less than 1 microamp) accuracy will be affected and the track of the potentiometer may be damaged. To ensure that this current is effectively zero it is advisable to build a servo pot into a signal conditioning circuit, as shown in figure 7, with a unity gain buffer (further explained in section 4.4).

The voltage Vb needs to be accurately stabilised since any change in Vb will produce a proportionate change in the angle measurement. In figure 7, an LM7805 voltage regulator is suggested as a means of stabilising Vb at 5v. Alternative types of regulators could be used for different values of Vb. Based on the circuit shown, if the servo potentiometer resistance varies from 0 ohms to 10,000 ohms (10k ohms) the voltage Vo will vary from Vb*R2/(R2+10,000) to Vb. R2 is indicated as 1k5, meaning 1,500 ohms. An alternative to having Vb accurately stabilised, or to improve on the accuracy possible with a simple voltage regulator, is to arrange for the computer to measure both Vb and the output and to correct the readings according to the measured changes, this costs nothing if there happens to be a spare ADC channel in the interface unit.

An optical encoder is another type of sensor for measuring angles. It contains a disc with opaque sectors which interrupt a light (infra red) beam as the disc turns so producing pulses in a light sensing circuit. Optical encoders are described as incremental or absolute. For the incremental type the angle of the disc is determined by counting the pulses from a known starting position. With an absolute optical encoder pulses are simultaneously generated on a series of output lines as the disc turns and reading the voltages on these output lines as a digital number indicates the angle of the disc without needing to know its starting position.

Generally, optical encoders are more expensive than servo pots, some much more so. Most optical encoders work over a full 360 degrees measuring range whereas servo pots have a sector of a few degrees over which no measurement is possible. Optical encoders often have lower friction than servo pots, although this is not always so. Optical encoders can be extremely accurate, although the cheaper ones are not always as good as a cheap servo pot. When I worked in development of land surveying instruments we had access to a fantastically accurate optical encoder for calibration, the claimed accuracy being 0.01 seconds of arc which is about the angle subtended by the thickness of a pencil viewed at a range of 100 kilometres. The accuracy possible with the more expensive optical encoders is unlikely to be necessary for applications in yacht research and so a servo pot. may offer better value and may also be easier to connect to the computer, assuming that an interface unit with ADC is available.

An optical encoder could well be the first choice for the measurement of a wind vane angle since it has potentially lower friction than a potentiometer. In AYRS booklet No. 119, George Chapman discusses the amateur construction of an optical encoder specifically for this application.

It is perhaps surprising that most yachting instrument systems do not include any means to measure the angle of heel. Angle of heel of a monohull sailing yacht is likely to be an important measurement in any detailed study of rig or hull performance and if combined with water speed measurement it can also provide an indication of the leeway angle. Another possible use for angle of heel measurement is to improve the accuracy of readings obtained from wind speed and wind direction instruments since these readings are certainly affected by large heel angles. The use of a pendulum attached to a servo potentiometer or possibly to an optical encoder is a simple, perhaps crude, approach to measuring angle of heel of a sailing craft. There are also sensors which are specifically intended for tilt measurement in industrial applications and some of these may be well suited to measuring the heel of sailing yachts. Such sensors are often electronic versions of the spirit level, the movement of some liquid within a small capsule being sensed electrically by capacitance or resistance probes. Another type, which is available from the Swiss company Wyler, contains a metal disc on a very soft spring mount. The disc moves as the sensor tilts and the movement of the disc varies a capacitance to produce an output. The Accustar tilt sensor available from Lucas Control Systems appears to be suitable for the accurate measurement of the heel of a sailing craft. This sensor has a range of 60 degrees each side of vertical and a claimed resolution of 0.01 degrees. Four options are available for the form of the output signal, these including an analogue voltage output and an RS232 output. The UK price is £86 regardless of the output option.

7.5 Linear Position Measurement

Sensors for measuring linear position over relatively short distances are often known as displacement sensors. Displacement sensors can sometimes also be convenient for determining angles and conversely angle sensors can sometimes be convenient for determining displacements.

As an example of the use of a displacement sensor to measure a small angle change, one might sense the angle of an adjustable pitch lifting hydrofoil by connecting a light push/pull rod to a displacement measuring device having a range of perhaps a few mm. By suitable choice of the geometry of this linkage the movement could be arranged to cover the full range of the measuring device. This would not be possible if the angular movement were directly connected to a servo potentiometer angle sensor since these generally have a full range of nearly 360 degrees. The readings of a measuring device connected to an input through some mechanical linkage may well be non-linear in that it will be affected by the changes in the geometry of the linkage. This is not a great difficulty if the measurement system includes a computer since the computer can be programmed with trigonometric relationships so as to calculate the errors and apply corrections. It is a great advantage of computer data acquisition that non linearity of sensors is in general not a problem as long as it is consistent and can thus be taken into account in the software.

As an example of the use of an angle sensor for measuring displacements, consider a light thread wound on a drum or pulley mounted on the shaft of an angle measuring sensor such as a servo pot. or optical encoder, the other end of the thread being attached to some object the displacement of which is to be measured. Systems based on this principle have been used to measure the co-ordinates of points on yacht hulls. I have used this kind of arrangement for an industrial application and it worked well but care is needed to ensure that the drum is accurately concentric and one needs a durable non-stretch thread. Fine stainless steel multi strand wire can be used and is available down to about 0.5mm diameter.

A simple form of displacement sensor is a **linear servo pot**. This works in the same way as the angle measuring servo potentiometer discussed above, but it has a linear rather than rotary action. Linear servo pots are typically available with measuring ranges of from say 10mm to 100mm. The cost tends to be more than that of a rotary servo potentiometer of similar quality. Linear servo potentiometers often have a spring loaded plunger which can be arranged to press lightly against a moving object so as to measure the position of the object relative to a datum. The signal conditioning required for a linear servo pot. is the same as for a rotary one.

A **linear variable displacement transformer** (LVDT) is an alternative to a linear potentiometer. It measures movement of an iron part relative to an AC energised winding. The cost is generally greater than for a potentiometer device and more complicated signal conditioning is required. Accuracy tends to be better than for a potentiometer device and the life may be longer since the wear of a wiper against a conductive track is eliminated.

There are several other types of displacement transducer with ranges both shorter and longer than the ranges usually covered by potentiometer and LVDT sensors. For example, capacitance and eddy current sensors can measure movements of microns or less and optically sensed glass scales or magnetically coded strips are fitted to machine slides to accurately measure movements of a metre or more.

7.6 Strain Measurement

In engineering, strain is a measure of how much a solid material is stretched and it is expressed as the extension of the material divided by the original length. A tensile (stretching) strain is given a positive sign, a compressive (squashing) strain a negative sign. The measurement of strain at the surface of a component is an indirect method of determining the stress within the material and hence determining how close the component is to its likely breaking point. This may indicate that the component is dangerously close to breaking and needs to be re-made to a stronger design, or it may indicate that the component is unnecessarily strong and could be redesigned to reduce weight. Strain measurement is particularly relevant to components which need to be both strong and light. Yacht spars are an obvious application and I understand that there is a research project on strain in yacht masts

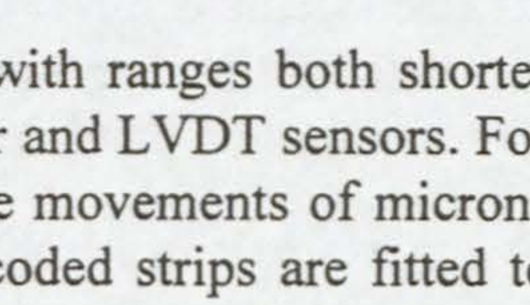


Figure 8 - Strain Gauge

presently being carried out by a spar manufacturer with part funding by the government. This project uses advanced optical methods for strain measurement but there is no reason why amateurs should not work in this field since measurement of strain using conventional strain gauges is fairly inexpensive.

Strain gauges, see Figure 8, consist of a fine grid of conductive tracks, usually mounted on a plastic backing, which can be bonded to the surface of a strained part using an adhesive, often epoxy. If the underlying surface is stretched i.e. strained, in the direction of the tracks the length of conductor in the grid increases and the cross sectional area of the conductor is slightly reduced and so the electrical resistance of the grid increases. Conversely the electrical resistance decreases if the underlying surface is squashed.

The change in resistance which occurs when a strain gauge is strained is quite small, the resistance scale of a digital voltmeter will show that there is a resistance change but most pocket meters will not have enough resolution to accurately indicate the magnitude of such a small resistance change. To measure the change in resistance it is usual to wire strain gauges into a bridge as fig. 9 below:

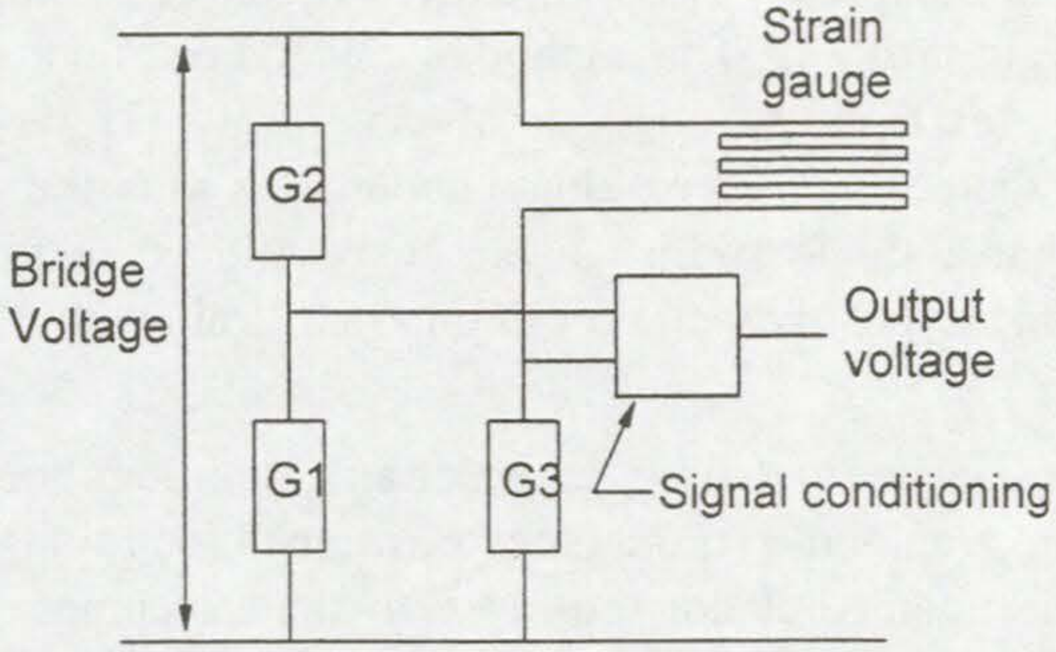


Figure 9 - A Strain Gauge Bridge with one strain gauge

The strain gauge and the three fixed resistors G1, G2 & G3 form the bridge and must all have the same nominal resistance, for many strain gauges this resistance would be either 120 ohms or 350 ohms. The block labelled ‘signal conditioning’ in Figure 9 is a differential amplifier circuit which receives two voltage inputs from the bridge and amplifies the difference between these voltages to produce an output which can be read on a meter, dislayed on an osciloscope of connected into a computer data aquisition system. The amplification factor between the output voltage change and the change in the difference between the input voltages is known as the gain of the amplifier, let us call this Ga. If the resistors G1, G2, G3 and the strain gauge itself all have exactly the same resistance it can be seen that because of the symetry of the bridge the inputs to the signal conditioning circuit will be at equal voltage and so the output will be zero. In this situation the bridge is said to be balanced. Any small change in the resistance of the strain gauge, as is produced by a strain of the material on which the gauge is bonded, will slightly unbalance the bridge causing a difference in voltage to the signal conditioning inputs and hence a change in the output. It is good practice to use precision grade resistors for G1, G2, G3 since these have better stability than standard resistors and the output is supposed to change only with the change in the strain gauge resistors, not with a change in the resistance of the other bridge resistors as could, for example, be caused by temperature effects. The proportionate change in strain gauge resistance is equal to the strain applied parallel to the gauge grid conductors multiplied by a factor known as the gauge factor, Kg, which is typically 2.5 for a foil type strain gauge.

Strain gauge readings are dependant on the alignment of the gauge on the surface. Even if a part is strained close to breaking there is usually a direction in which there is no surface strain, ie. no stretch in the surface and a strain gauge will give a zero reading if the grid conductors are aligned in this direction. In some cases it is difficult to guess the pattern of strain in the surface and it is then necessary to use strain gauges in closely spaced groups of three gauges aligned at angles to each other, these being known as gauge rosettes. Knowing the angles between the gauges in the rosette and the properties of the material under the gauges it is possible to use the gauge readings to completely determine the state of stress of the material and hence how close it is to breaking. The method of calculation is not all that simple but is explained in any textbook on strength of materials. However, it is usually possible to simplify the problem by making a good guess as to the way the surface is being strained so that a single strain gauge can be aligned to give the maximum strain reading for tensile (positive) strain or minimum strain reading for compressive (negative) strain.

To take an example relevant to sailing, consider an aluminium boom bending under the load of a kicking strap and a strain gauge positioned longitudinally on the upper or lower side of the boom, but not too close to the fastenings which secure the kicking strap - see figure 10.

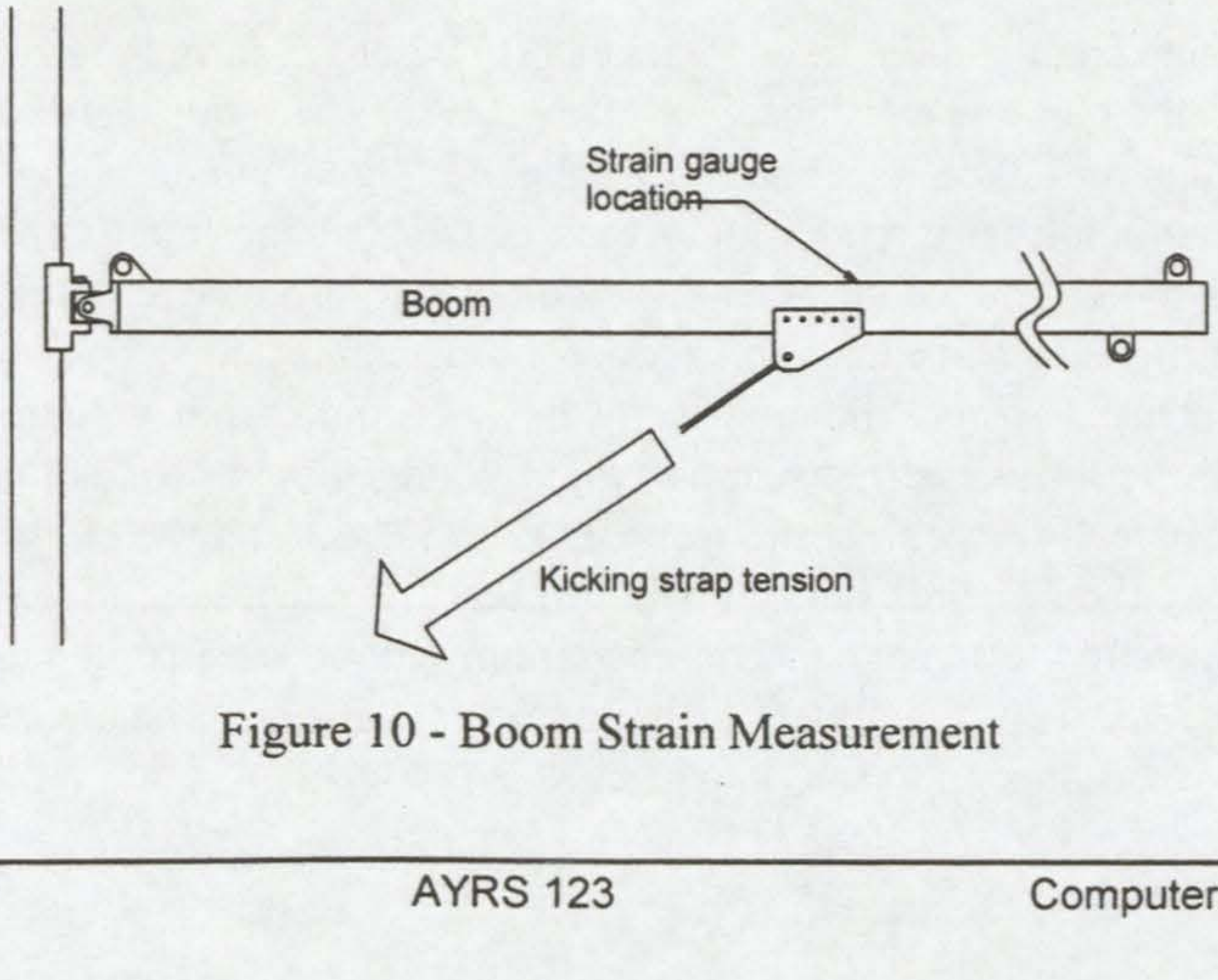


Figure 10 - Boom Strain Measurement

It is a reasonable guess that the strain in the boom is mainly due to bending causing longitudinal tensile strain on the under surface of the boom and compressive strain on top. In this relatively simple situation a longitudinally aligned strain gauge below/above the boom can be used to determine the tensile/compressive stress in the material using the relationship:

$$\sigma = E\zeta$$

where: σ = Direct stress - N/mm^2
E = Young's modulus for the material N/mm^2
ς = Measured strain

Young's modulus is a measure of the stiffness of the material when tested in tension or compression. It is not necessarily related to the strength of the material since stiff materials can be weak and strong materials can be quite stretchy. Young's modulus for aluminium is about 70,000 N/mm^2 (70,000 MPa - Megapascals).

Let us suppose that the boom mounted strain gauge is wired into a bridge circuit as shown in figure 9. Suppose:

Output voltage change when boom is loaded, Dv = 5v

Amp. Gain, Ga=500 Bridge voltage, Vb=5v Gauge factor, Kg=2.5

then strain, ς = Dv/(GA*Vb*Kg) = 5/(500*5*2.5) = 0.0008

A strain of 0.0008 is often referred to as 800 microstrain (+ve for tensile strain). Strain values are specified without dimensions since they are simply the ratio of two distances. A strain of 800 microstrain means that the surface has stretched by a factor of 1.0008. Using the value of Young's modulus given above the corresponding tensile stress is 56 MPa, ignoring any stress concentrations due to fastener holes etc. The tensile yield stress of HE30TF aluminium alloy, which is a typical material for yacht booms, is around 250 MPa and so the factor of safety based on yield strength is 250/56 = 4.5. A factor of safety of 4.5 based on yield strength may be a reasonable factor of safety but considering the possible effect of local stress concentrations associated with the kicking strap attachment fittings and the susceptibility of aluminium to fatigue failure at points of stress concentration it is probably not advisable to winch the kicking strap in too much further. You would need to consult a text book on strength of materials for more detailed material strength properties and stress concentration factors.

In practice, if the boom is a large thin-walled section it may fail by buckling, that is crumpling, of the upper side rather than by yielding of the lower side. In this case the bending moment in the boom may need to be kept lower than that corresponding to tensile yielding of the material, but a strain gauge placed on the top or bottom surface of the boom will still serve to monitor the bending moment carried by the boom and to provide a warning when this bending moment approaches that which would cause buckling as determined either experimentally or by a buckling analysis.

In aerospace industry strain gauges are used in this manner for research and development purposes and sometimes also for routine in-service monitoring of heavily loaded components such as aircraft undercarriages and wing spars. Parts of yachts where this approach might be justified could include spars, standing rigging, the hull skin in areas affected by pounding, the rudder stock and keel attachments. For multihulls this list could also include the cross beams and the hull skins in the region of cross beam attachments.

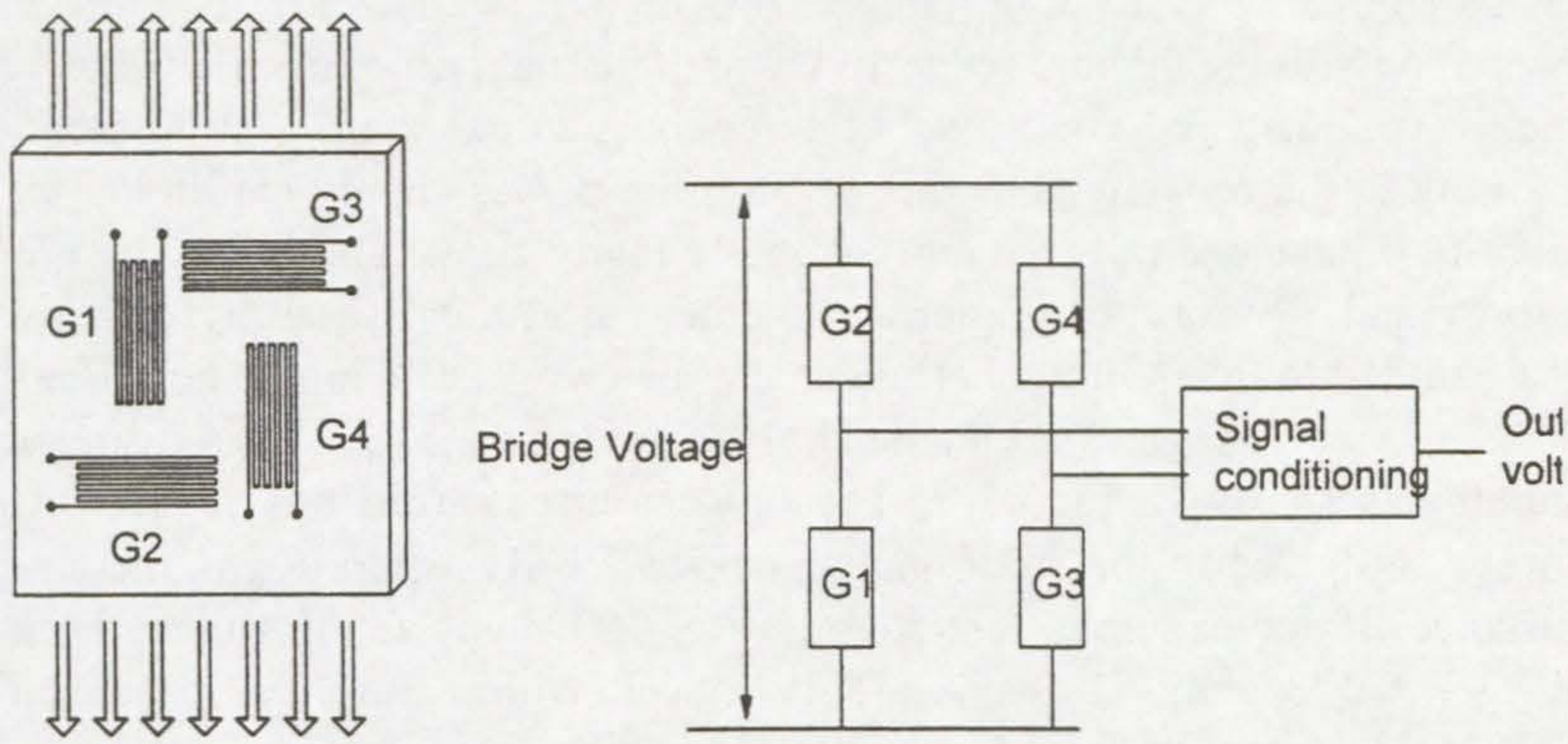
7.7 Force Measurement

Force measurement in yacht research could include the measurement of loads in rigging wires, mast compression or bending load, hydrodynamic forces on models or full sized craft under tow, forces on kite/spinnaker lines or in the mooring lines of a craft moored with sail set so as to determine aerodynamic forces. I have included quite a lot of detail on force measurement in this booklet since it is a measurement which is likely to be needed in a lot of yacht research projects but is not included with most commercially available yacht instrument systems.

Sometimes it is possible to measure such forces by balancing them against a spring balance or against dead-weight loads but these methods tend to require bulky and/or heavy apparatus which cannot easily be built into a computer data acquisition system. Also there may be difficulties in using a spring balance with fluctuating loads since the resulting spring mass system may have a fairly low natural frequency leading to resonance and erratic readings. Often it is better to use electrical force sensors which are often based on strain gauges as are discussed in section 7.6 above. A component which is fitted with strain gauges so that it can be used as a force measuring device is known as a load cell. Load cells can be designed to suit a wide range of loads and are well suited to large loads, loads of many tons are no problem. For light loads, such as the drag of a small boat or a model hull being towed at low speed, it may be worth considering alternative types of electrical force sensor, for example there is a neat device from Honeywell which measures to 1.5 kg. using a piezoresistive element (Radiospares cat. No. 235 6210).

A crude load cell could consist of a single strain gauge bonded onto a loaded rod or plate and aligned to sense strain in the direction of loading. The strain gauge could be wired into a bridge circuit as shown in Figure 9 and the measured output would be proportional to the applied load and so an unknown load could be determined once the device has been calibrated using known loads.

Figure 11 shows an improved load cell compared with figure 9, although it is still a crude design. This load cell has four gauges, each of which forms one 'arm' of the bridge circuit and so the three fixed resistors shown in figure 9 are not required. This arrangement is known as a four active arm bridge. If the plate is loaded in the direction shown by the arrows, then G1 and G4 will be stretched and G2 and G3 will be squashed, as can be imagined if you consider what happens to the thickness of a loaded elastic band. The squashing of G2 and G3 is typically about one third of the stretching of G1 and G4. The use of a four active arm bridge gives more output signal than a bridge with a single active arm, provided that the gauges are correctly wired so that the effect of the resistance changes of the individual gauges add to each other rather than balancing each other out. Another advantage of using bridges with four strain gauges is that resistance changes of the gauges due to temperature change tend to cancel out.



A simple load cell (wiring omitted)

Wiring the gauges into a bridge

Figure 11 - Simple Load Cell

Load cells are designed to give high strain values at the locations of the strain gauges and this typically produces an output voltage from a four active arm bridge of around +/-20 millivolts when the load-cell is loaded to its maximum safe load and with a 10 V bridge voltage. If this output were to be read by a computer interface unit with an input range of say 10 volts then the signal conditioning amplifier needs a gain of about 100. When reading the strains in individual gauges bonded to parts such as spars, e.g. as figure 10, the bridge output will be lower and amplifier gain may need to be as high as a few thousand. Increasing the bridge voltage increases output but too high a bridge voltage will overheat the strain gauges. Strain gauges used for load cells can be reasonably large so dissipating more heat and allowing the bridge voltage to be up to about 10v or so. Miniture strain gauges used for studying localised stress concentrations require lower bridge voltage.

Figure 12 shows an amplifier which can be built using the construction methods discussed in Section 8 below. The amplifier gain can be adjusted by changing the values of certain resistors in the circuit, or, if preferred, variable resistors can be used. I generally prefer fixed resistors, to avoid the risk of them being altered inadvertently. The four strain gauges G1 to G4 are shown connected by a screened multicore cable to the rest of the circuit which would normally be built on some kind of circuit board. If only a single strain gauge is used the other bridge arms would consist of precision fixed resistors mounted on this circuit board.

This amplifier includes two op-amps, which can be conveniently in the form of a single dual op-amp integrated circuit. Numerous types of dual op-amps would be suitable, one I have used with the circuits shown in this booklet is LT1078CN8. This has eight pins, numbered as shown in the inset diagram and as numbers adjacent to the triangular amplifier symbols on the main circuit diagram. Many other types of dual op-amp have similar pin numbering. The pins 4 and 8 are for the -ve and +ve power supply to the op amp respectively and the diagram omits the 0.1mF capacitor which it is considered good practice to connect across these pins in close physical proximity to the op-amp. For this op-amp the power supply can be up to +15 and -15 volts if balanced rails having voltages equally above and below 0v are used, or up to 0v and 30v for the simpler arrangement as shown which has the low voltage rail grounded to 0v. With this arrangement a 12 volt DC supply should be fine. The bridge supply voltage, Vb can be derived from this DC supply using a voltage regulator as shown in Figure 7. The power current from this regulator is almost entirely dissipated in the strain gauges and is Vb/Rg where Rg is the strain gauge resistance. If for example, Vb=5 volts, Rg=350 ohms (350R) then the current is Vb/Rg = 0.143 amps (143 mA). This is well within the 1.0amp capacity of the LM7805 regulator fitted with a heat sink, in fact several such load cells could be powered by one such regulator.

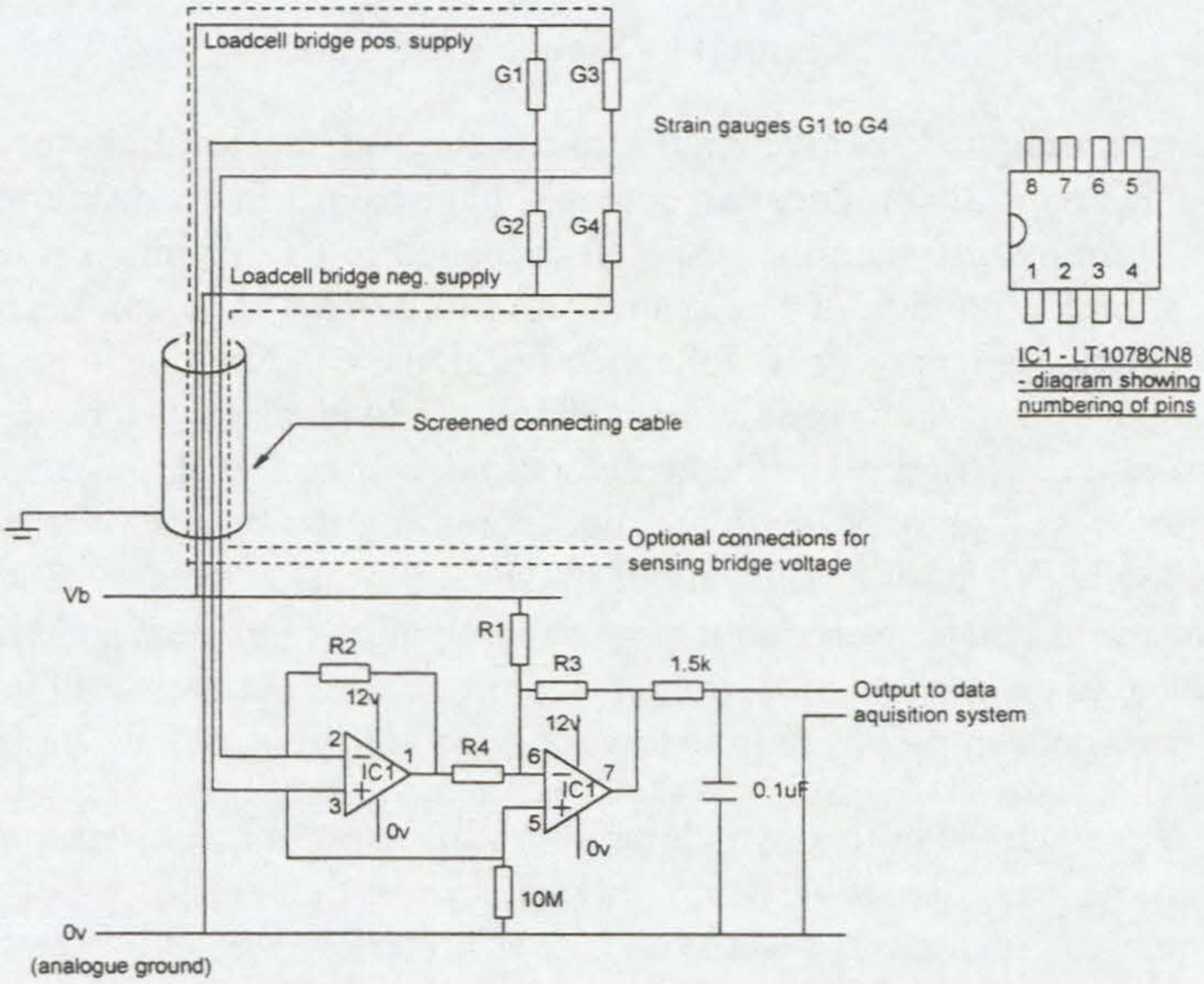


Figure 12 - Strain Gauge Bridge amplifier

The operation of the circuit shown in Figure 12 can be understood if we remember that the op-amps try to keep their +ve and -ve inputs at the same voltage by adjusting their outputs. Without the amplifier connected, the bridge would become unbalanced when G1 and G4 are under compression and G2 and G3 under tension (or vice-versa). When the amplifier circuit is connected to the bridge it cannot tolerate this situation since the left hand op-amp wants to keep its inputs (points 2 & 3) at the same voltage. It corrects the imbalance by passing sufficient current from output 1 through R2 into the bridge to compensate for the unbalance of the strain gauge resistances. Without going into the algebra, the change in voltage at point 1 is greater than the output of the bridge without amplifiers connected by a factor of 2*R2/Rg, where Rg is the resistance of any of the individual strain gauges. The right hand op-amp provides a second stage of amplification to further boost the output as measured at 1. If we assume initially that R1 is not present, the right hand op-amp wants to keep 5 and 6 at the same voltage and does so by making the voltage change at 7 bigger than that at 1 by the ratio R3/R4. The overall gain of the amplifier is the gain of the two stages multiplied together ie. (2*R2/Rg)*(R3/R4). A suitable value for R4 would be 10000 ohms (10k). Thus, if we wanted an overall gain of 900 we would normally make the first and second stage gains about equal, ie. each stage should have a gain of about 30 and with 350 ohm gauges R2 would be 15*350 and with R4=10k, R3 would be 30*10k. Resistors are only available with certain standardised values so we might choose 5k for R2 and 330k for R3.

The effect of R1 is to shift the voltage at 7 by a fixed amount regardless of the changes in strain gauge resistances. This can be used to adjust the output voltage at the zero load condition. Remember that, as with the circuit shown in figure 6, the output at 7 should not come too close to the supply rails, although with the LT1078 it is possible to go quite close to the rails, say within 0.5 volts. This means that if you are measuring a load which is always on one side of the zero load condition you could adjust R4 to make the output 0.5V at no load and wire the bridge so that the output becomes close to the positive supply rail at full load. If bi-directional measurement is needed, i.e. the loadcell is subject to loading which may be equally above or below the zero load condition, then R4 will need to be adjusted to make the output at the zero load condition about midway between the supply rails.

The dotted lines in Figure 12 show additional cable connections leading to the strain gauge bridge and connected so that they can be used to measure the value of Vb independently of any voltage drop which may occur along the current carrying connections to the bridge. It is suggested above that a regulator such as a 7805 could be used to stabilise the voltage Vb, and whilst this may be good enough for many purposes it may not be good enough for precision work. A better level of stabilisation for Vb and may require the voltage measuring connections shown dotted in the diagram to be taken back to the voltage regulation circuit which controls Vb. There is another alternative which is to stay with a simple regulator but to arrange for the computer to measure both the output and the Vb value as sensed at the bridge. When the loadcell is calibrated the overall system gain can then be worked out in terms of a numerical output per N of load and also per volt of bridge voltage, allowing the measured loads to be calculated using the measured values of Vb. The same method is applicable to measuring angles using a servo-potentiometer circuit as discussed in section 7.4 above.

Even when the strain gauges are under a steady strain, the voltage as measured at point 7 will not be perfectly stable and if this voltage is examined using an oscilloscope it will be seen to have a small high frequency pulsation which is undesirable but inevitable due to imperfections in the behaviour of the components of the circuit as well as interference from outside the circuit. The final two components shown in the circuit are a 1.5k resistor and a 0.1mF capacitor and these act as a low pass filter which partially damps out this high frequency pulsation. The values of one or both of these components can be increased to increase the damping and this may be necessary if there is a lot of interference. The low pass filter also makes the circuit less sensitive to rapid changes in strain, so if very fast response is needed the low pass filter may need to be removed or smaller component values used. Force measurement applications in yacht research will in general not require particularly fast response and so the use of a low pass filter with values as suggested in Figure 12 is probably acceptable.

Strain gauge circuits are more sensitive to interference than most of the other sensing circuits discussed in this booklet. The effect which interference has on the accuracy of readings can often be reduced by using low pass filter or by arranging for the computer to take a lot of readings in quick succession and then to average the results, this being known as a numerical low pass filter. However, it is still best to try to keep the interference to a minimum to begin with.

An oscilloscope can be used to examine signals for interference. It is unlikely to be worth purchasing an oscilloscope unless you are taking up electronics as a fairly serious hobby in itself, but if you suspect that your signals are suffering unduly from interference then you need to get them checked by someone who does have an oscilloscope. Simple precautions to minimise interference include the use of screened and twisted cable to connect between the strain gauges and the amplifier circuit. Alternatively these connections can be made very short, but this is not always convenient. Note that the cable screen should be connected to ground at one end only, a cable screen which is grounded at both ends forms an 'earth' loop and may be worse than useless. It is also desirable to keep the signal conditioning circuits clear of large sources of interference such as electric motors. Computers and other equipment which processes digital signals are also potential sources of interference but generally they should be designed with screening and other precautions to minimise the effect on equipment installed nearby. If it is necessary to position strain gauge signal conditioning close to an inadequately screened motor or computer, then it may be necessary to build the strain gauge amplifier(s) in a fully enclosing metal or metal coated box and to have the screens of the lead(s) to the strain gauge(s) connected to this box.

It is possible to home build load cells and the associated signal conditioning for much less than the cost of ready made equipment, although if time is money this may not be true. For making the load cells, metal working machinery would help, but is not essential for the simplest designs. For a home made load cell the strain gauges are likely to be the most expensive items costing two or three pounds each and as discussed above, four strain gauges would normally be required for each load cell. The easiest strain gauges to use are probably those which are supplied with fine connecting leads, 25mm or so in length, already attached. Care should be taken to follow to the letter the manufacturer's guidance on bonding the strain gauges onto the metal surface and coating them to minimise the effect of moisture penetration. Strain gauges which are not properly bonded are useless and if one is unsure of the bonding technique it is best to consult the strain gauge supplier. If the instrumentation is to last any length of time in a marine environment the gauges and leads must be carefully protected against mechanical damage and sealed against moisture. Silicon rubber sealant is useful for encapsulating the wiring to the gauges but it is best to avoid the cheap type which smells of vinegar since this can itself be corrosive. For marine use it would be best to make load cells from stainless steel or high tensile aluminium e.g. at least H30TF grade aluminium and preferably H15 grade, or 316 stainless. Stainless steel can take a higher load than aluminium but the electrical output which can be achieved is not much different since stainless steel is less than half as stretchy as aluminium alloy (This booklet deliberately avoids mathematical descriptions!) - it has a Young's Modulus of 200,000 N/mm^2 against 70,000 N/mm^2 for aluminium alloy.

Usually a load cell is required to measure load acting in a particular chosen direction and to be insensitive to any other loads applied to it. The crude load cell shown diagramatically in Figure 10 would not be a good in this respect since it would definitely be sensitive to bending of the plate as well as stretching. It would help a lot to have the gauges G3 and G4 on the reverse side of the plate to counteract this effect and to shape the plate with a narrow section where the gauges are mounted, so as to increase strain in this area whilst leaving plenty of material at the ends for attachment of the load to be measured. These refinements lead to the arrangement shown in Figure 13, which shows three plates between two D-type rigging links.

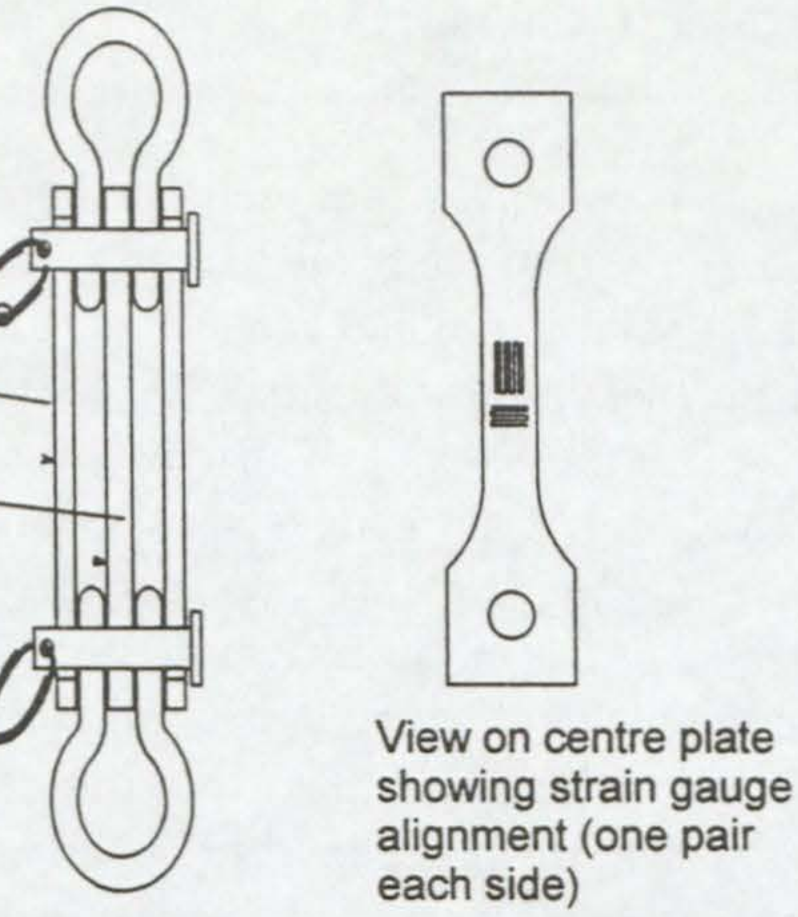


Figure 13

The two outer plates in Figure 13 are optional and are to provide a backup in case the weaker centre plate should break. Most load cells do not include such a backup arrangement but it may be a wise precaution if failure of the loadcell would be catastrophic, e.g. if the loadcell is built into standing rigging. These outer plates have slotted holes, these giving a clearance on the clevis pins so that the plates do not carry load. The strain gauges are bonded to both sides of the centre plate which is necked to increase the strain in the area of the gauges. The four core connecting cable could be clamped to one of the outer plates and the lead connections and gauges encapsulated with silicon rubber. This level of protection should be good enough for short term experiments but definitely not for permanent marine installation. The cross sectional area of the necked region of the centre plate where the gauges are mounted should be such as to give a value of 1000 to 1500 microstrain when the loadcell is fully loaded (assuming the material is either high strength aluminium or high strength stainless steel). Higher strain will increase the risk of breakage, especially with fatigue loading, and lower strain will give an unnecessarily low sensitivity.

Let:

Intended full load of loadcell	=	F (N)
width of the necked region of the strain gauged plate	=	w (mm)
thickness of the strain gauged plate is	=	t (mm)
stress concentration factor	=	C

then the stress σ (N/mm^2) at the strain gauges is given approximately by the formula:

$$\sigma = \frac{CF}{wt}$$

For the geometry shown in figure 13 the stress concentration factor, C, can be assumed to be unity.

A full load strain of 1000 microstrain is a good target for either steel or aluminium loadcells. If the material is stainless steel having E=200,000 N/mm², then we are aiming for a stress (s) at full load which is 200,000*0.001 = 200N/mm². We thus need to choose values for w and t which will suit the material to hand in the scrap box and which will also give roughly this stress at the intended full load. For example, if we wanted to measure a maximum load of 0.5 tonne, approximately 5000 N, wt would be 5000/200 = 25mm² and so the cell could be made with a 14 gauge plate (2mm thick) having a necked region about 12.5 mm wide.

Companies such as Strainsert supply special clevis pins which act as load cells and can be used with standard cable terminals, rigging links etc. These would be very suitable for measuring rigging loads since they are available totally sealed for marine use. However, they are fairly expensive and not easy to copy in the home workshop. The internal arrangement is a small hole drilled down the pin axis and two four gauge strain gauge bridges mounted internally on the bore of this hole with the gauges inclined 45 degrees to measure the shear effect in the pin.

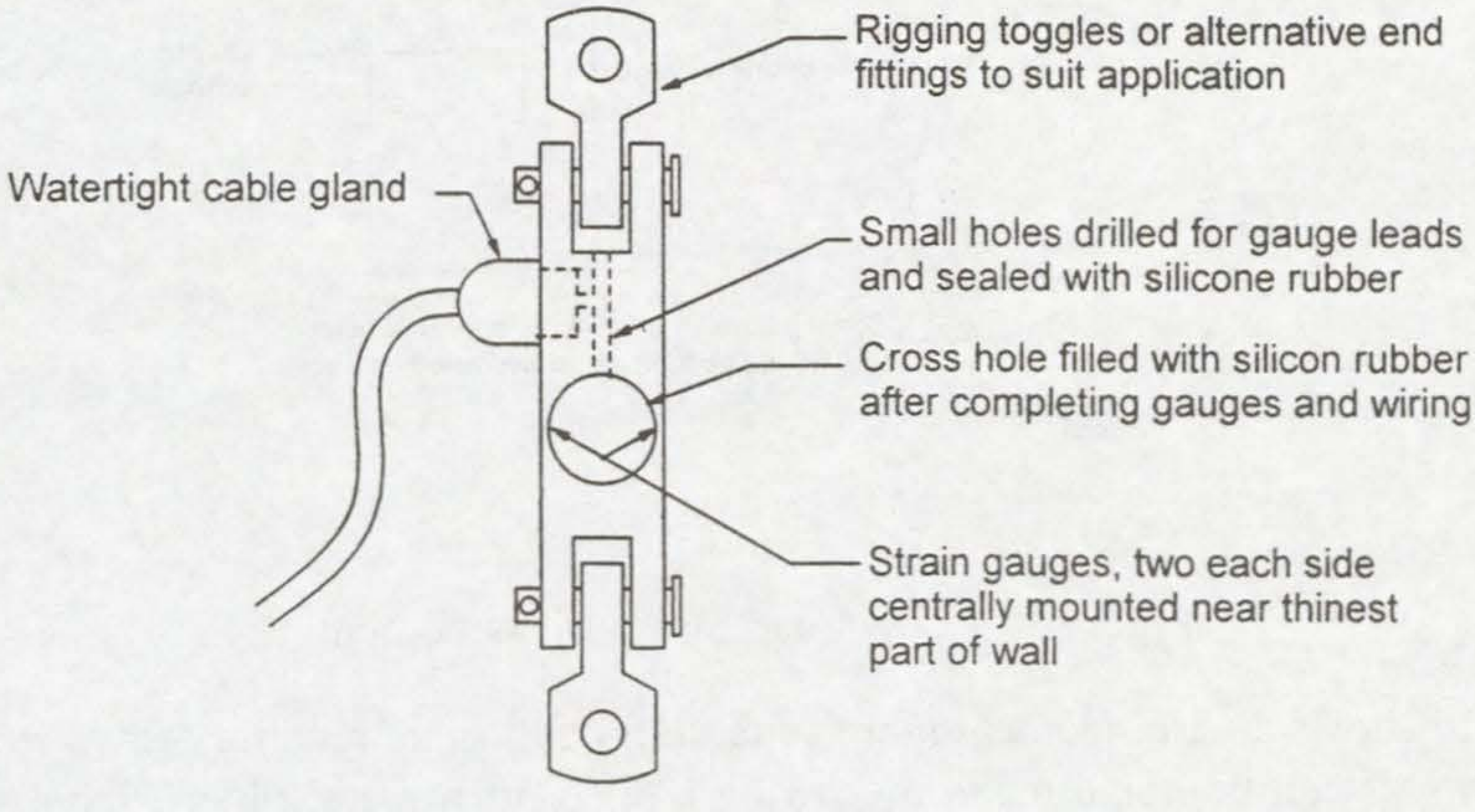


Figure 14

Figure 14 shows an arrangement which is not as neat as the clevis pin type load cell but which should provide reasonable protection for the gauges and wiring whilst being just about feasible for home construction. A cross hole is carefully bored through a rectangular section bar (a round bar might also be suitable), the hole diameter being almost the width of the bar so as to leave two necked sections, the combined area of which can be calculated in the same way as for the load cell shown in Figure 13 but allowing a stress concentration of say 1.5 rather than unity. The gauges are bonded to the inner surface of this hole and the hole is filled completely with silicon sealant after completing the wiring. It is more tricky to mount the strain gauges on the inside of the hole but do not be tempted to mount them on the outside, not only will they be poorly protected but the output will be small since the stress concentration factor will then be less than unity. To provide really good protection, the leads can be taken through small drilled holes to a four core connecting cable fitted into a watertight cable gland. Load carrying cables can be attached to the ends of the bar by pins through cross holes. As with the arrangement shown in Figure 13, loose fitted side plates, or a surrounding outer tube, (not shown) can be used to provide a backup in case of failure. Figures 13 and 14 are both drawn to suggest the load cell being at the termination of a cable as would, for example, be required for measuring forestay load, but similar arrangements could be used as connecting links in, for example, the attachment of lifting hydrofoils or floats or as part of a steering mechanism etc.

Both the arrangements shown in Figures 13 and 14 are best suited to fairly large loads, e.g. rigging loads. If one works out the cross section area for the waisted strain gauge section for light loads, one will find that it becomes impractically small.

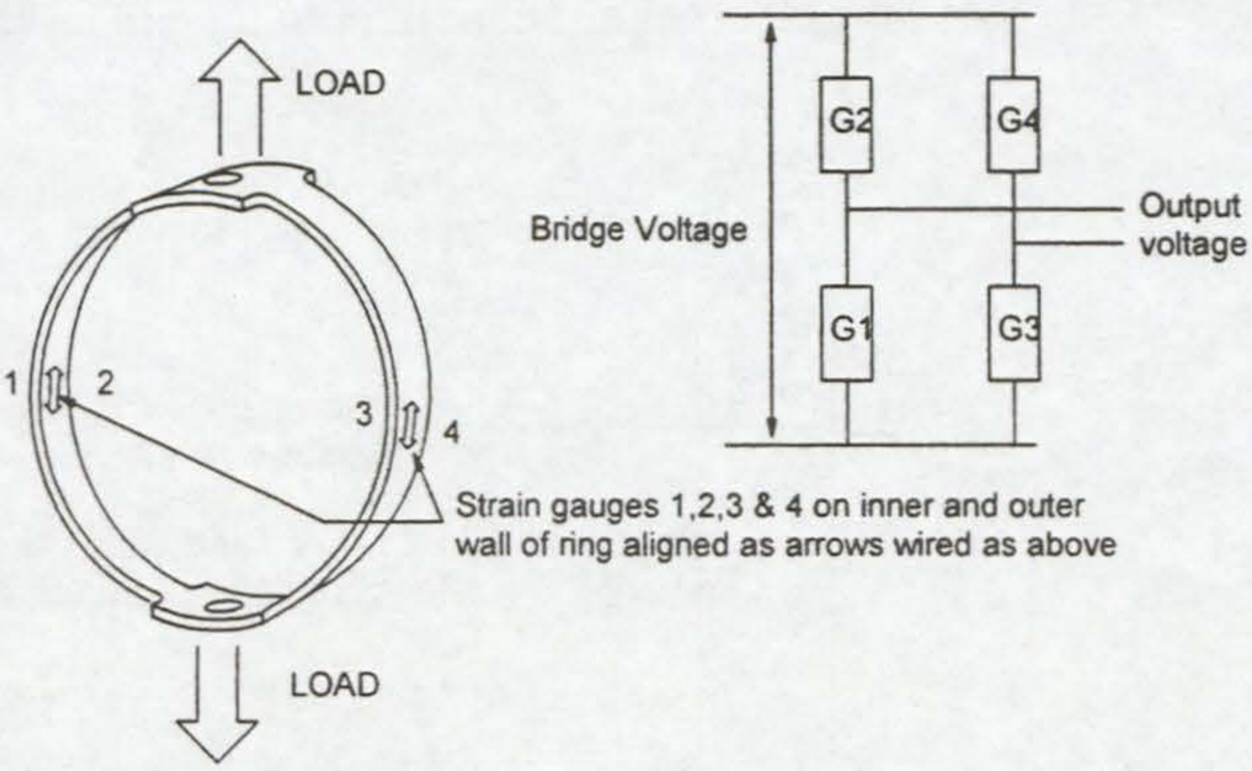


Figure 15 - Low Load Strain Measurement

Figure 15 shows an arrangement more suitable for full scale readings down to a few kilograms. It can be home made by sawing a slice off a metal pipe. I have seen a similar one used for measuring the strength of patients' leg muscles in a medical research project. The load F is applied to the ring in the direction shown by the arrows. The ring should ideally be reinforced around the area where the load is applied, by making it wider and/or thicker at these points, but the device will work reasonably well without this refinement. The load can be tension or compression and for measuring the tension load in a cord the cord can be simply passed through the holes in the ring and secured with a stopper knot on the inside.

If the width of the ring (in the axial direction) is w, and the thickness of the ring (in the radial direction) is t, and the diameter of the ring to its mid thickness is D = 2r, then the stress σ at the strain gauges is given approximately by the formula:

$$\sigma = 1.09\frac{Fr}{wt^2}$$

Knowing the maximum expected load F, this formula can be used on a trial and error basis to find suitable values of r, w and t which will produce a level of stress to give the target strain level based on the E value for the material of the ring.

Figure 16 is also suitable for small loads but these loads must be applied at a constant angle to the bending beam. If the load is applied through a cord then a pulley could be used to keep the cord aligned but the readings will then be slightly affected by friction in this pulley. It is important that the method of attachment of the cord sets the true point of loading fairly accurately. If the cord is taken through a hole in the spring then this should be a small hole.

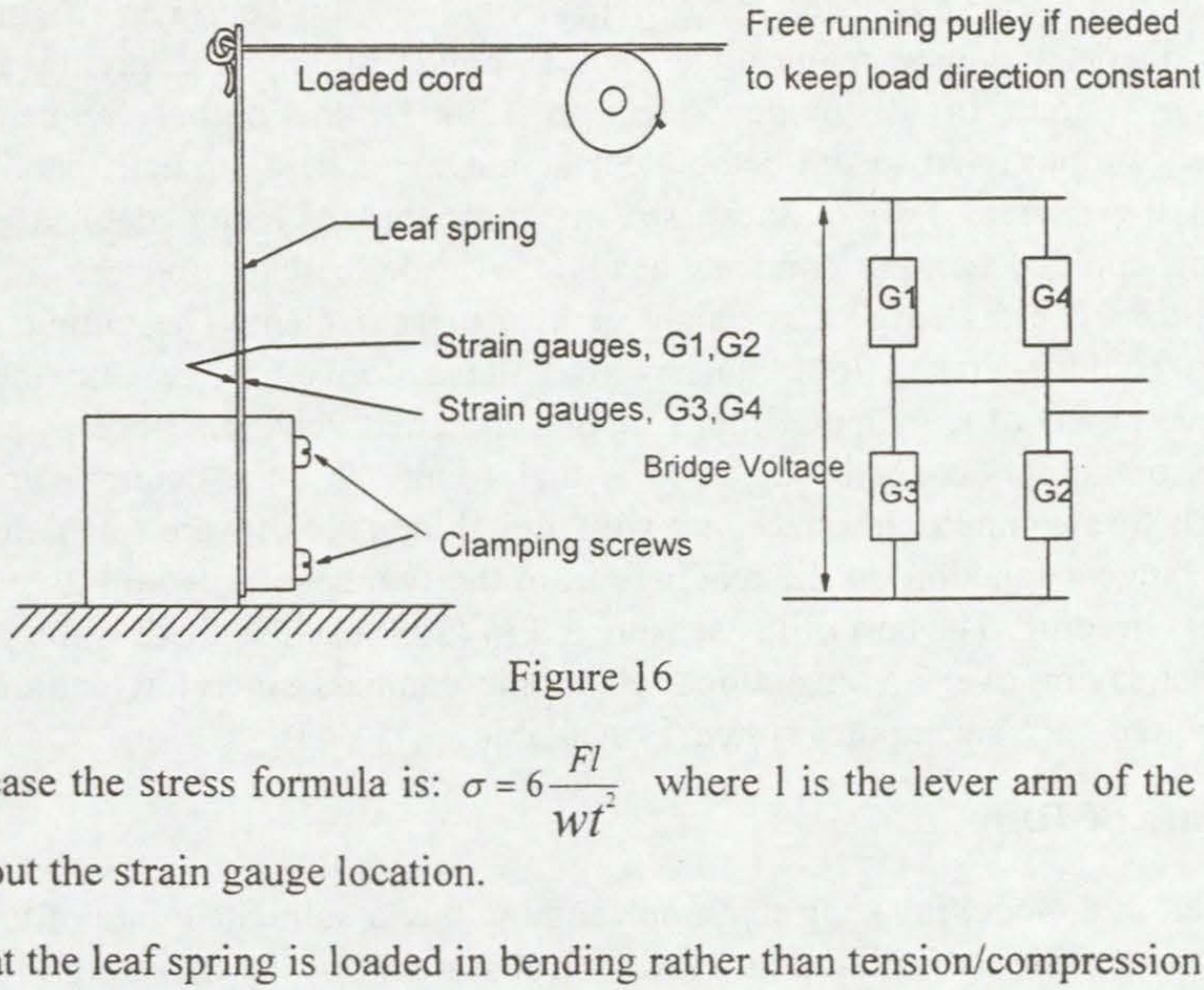


Figure 16

In this case the stress formula is: $\sigma = 6\frac{Fl}{wt^2}$ where l is the lever arm of the loaded cord about the strain gauge location.

Note that the leaf spring is loaded in bending rather than tension/compression and so all gauges are longitudinally aligned on the spring.

Having constructed a loadcell and the associated signal conditioning circuits it is now necessary to calibrate the system. The aim is to produce two calibration constants, one being overall gain, i.e. the output per Newton of load and the other being the output at zero load. Output could be expressed in volts but when calibrating a complete data acquisition system it is probably better to consider the output to be the actual number read by the computer, the exact voltage which this number represents is then not important. The calibration can be done by hanging known weights (dead-weights) on the loadcell whilst using the computer data acquisition system to measure the output. Loadcells are usually very linear in response provided that they are not overloaded, but even so it is best to check this by plotting a number of points and fitting a best straight line if necessary. With suitable software the plotting and line fitting can be automatic. Calibration of loadcells should be checked at intervals and to make this convenient it is a good idea to build calibration facilities into data acquisition software which uses loadcells, and for that matter any other type of sensor for which periodic calibration is desirable.

7.8 Determining Compass Heading

Electronic compasses are becoming increasingly popular and many of them are provided with an NMEA interface so that their readings could be read by a computer (see section 7.12 below). An alternative for the DIY enthusiast could be to build a system based on magnetic field sensors which use the same fluxgate principle as a ready made electronic compass. A magnetic field sensor which is claimed to be ideal for this purpose is listed in Section 11 below. This sensor is a 65mm long x 16mm diameter device requiring a 5v DC power supply and giving a variable frequency output in the range 50kHz to 120kHz, the output frequency being inversely proportional to the component of magnetic field strength parallel to the axis of the device. Two of these sensors orthogonally mounted on a gimballed platform could determine compass heading. An angle sensor on the fore and aft gimbal axis could also give an angle of heel measurement. The outputs from the sensors could be taken to frequency to voltage converter ICs and then to the analogue inputs of a computer interface unit. Alternatively, and perhaps preferably, the sensor outputs could be taken to a dual counter IC, the counts being read at intervals by a computer interface unit with digital inputs. Software calculations using an arc tangent function on the readings from the two sensors would give magnetic compass heading. The cost of the sensors is £14 ($23) each so there is the possibility of a cost saving over a conventional electronic compass since few additional parts are required once a computer system is available.

7.9 Rate of Turn

I noticed in a model/toy shop that one can now buy a solid state rate of turn sensor which is intended for building into the control system of a toy helicopter. It occurred to me that this sensor could be useful if one were building a computer controlled autopilot system. Feeding rate of turn information into the error signal which is used to control rudder position could be one way to avoid the excessive hunting which can be a problem even with commercially produced autopilots.

7.10 Data from the Global Positioning System (GPS)

Most GPS systems, even the small hand held ones, are available with a data output cable for connection to a computer allowing data from the GPS to be used by software in the computer. The most obvious application for such data is for electronic chart plotting as discussed in Section 10 below.

Apart from using GPS data for chart plotting, such data could also be used with programs written for yacht research purposes. As discussed in section 7.2 above, a GPS unit will produce a position which is accurate enough to determine average boat speed over some distance. It also provides position relative to an earth based reference frame and so combining GPS data with heading data from an electronic compass and tidal stream data, if this is significant, could give an indication of leeway angle which is otherwise an elusive item of data. It is not at all easy to measure leeway angle from the water flow adjacent to the hull since the hull itself has such a significant effect on this flow.

Most GPS systems output data in NMEA0183 format and reading such data into a computer program is discussed in Section 7.12 below. It is now also possible to purchase GPS sensors intended only for use with a computer. Such sensor units have no display or buttons, they simply acquire data from the satellites and pass it to a host computer. If a computer is permanently installed on a yacht, this kind of arrangement is logical since a computer offers a better display and more flexibility and ease of control than is possible with the tiny display and keyboard on most stand-alone GPS systems. If one is entirely dependent on the GPS for navigation it might be wise to also have a hand held GPS for backup. One might think that a GPS sensor with no display or buttons of its own would be much cheaper than a stand alone GPS unit but unfortunately this is not the case. Presumably the savings due to the high volume manufacture of stand alone GPS systems outweigh the saving due to omitting the display and buttons.

A GPS sensor unit for use with a computer may be a small robust box with a cable to carry NMEA0183 data to the computer. Alternatively, such a sensor may be an unboxed circuit board e.g. an ISA board, which can be fitted inside a desktop computer or a PCMIA card which can be slotted into a portable computer. This arrangement is particularly convenient since the unit will connect directly into the computer circuits avoiding connecting cables and the need for the computer to interpret NMEA0183 signals.

Position data from the GPS system is subject to random errors due to selective availability and also to a lesser extent due to atmospheric and other effects. The errors due to selective availability can be corrected by use of differential GPS whereby correction data is received from transmitters operated by organisations which in most cases make their revenue by charging for this service. Differential

GPS is not globally available and it is expensive both in terms of the extra electronic equipment required on board and the license fees paid to the operating companies. However, if a GPS is built into a computer based data acquisition system together with boat speed, compass heading and possibly other sensors then it should be possible to improve on the accuracy of standard GPS without paying for differential GPS. I see no reason why an amateur with some computer experience should not produce simple software to do this.

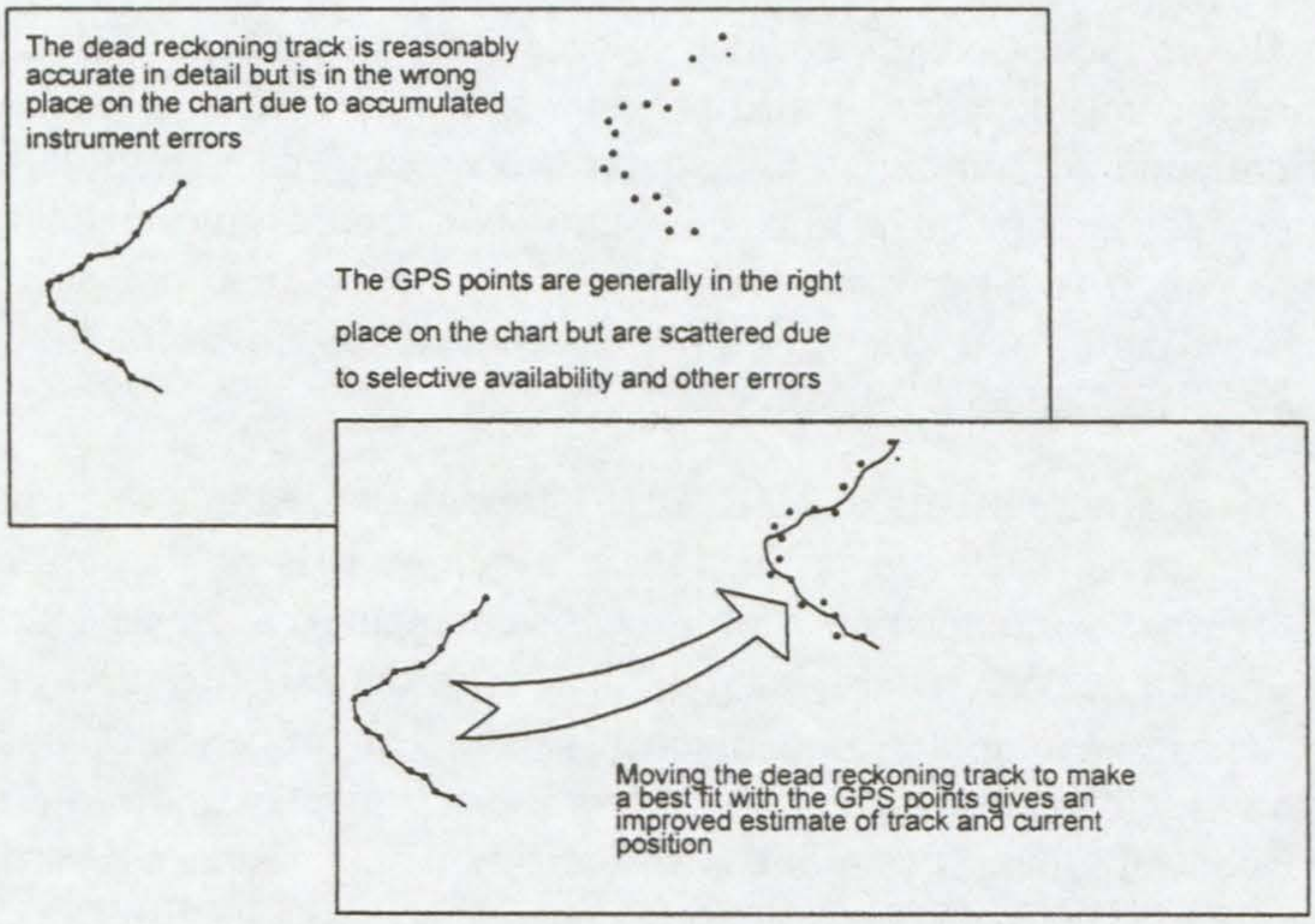


Figure 18

Suppose an accurate electronic compass, either the magnetic or gyro type and an accurate log are built into a system as described in this booklet. The computer can then use the readings from these sensors to work out the track of the boat. This is effectively automated dead reckoning. It can be expected to be more accurate than traditional dead reckoning since the computer can do the sums very accurately and it can update the position at very short intervals, but because of accumulating instrument error it will still be a relatively inaccurate positioning system for use over the length of a passage. Suppose we plot on a chart, as shown in Figure 18, a series of such dead reckoning fixes and also a series of GPS fixes taken more or less simultaneously. The track given by the dead reckoning is accurate in shape to perhaps a few metres, but it is in the wrong position on the chart due to accumulated instrument error. The GPS fixes are generally in the right place on the chart since averaged GPS data is accurate to 100 metres or better, but the individual fixes are scattered about due to selective availability and other effects.

We now need to 'slide' the dead reckoning track across the chart so as to position it to give the 'best fit' with the GPS fixes as shown in the lower section of Figure 18 and we can then take the current position of the boat from this repositioned dead reckoning track. A simple method to do this is to calculate the 'centre of gravity' of each track and then to displace the dead reckoning track by the difference in the co-ordinates between these centres of gravity. Each time new data is available the centres of gravity can be recalculated by setting up running averages for the x and y co-ordinates. There may be better, but more complicated methods, which in addition to translating the dead reckoning track also improve the fit of the tracks by applying a variable scaling and rotation of the dead reckoning track to allow for possible errors in the log and compass sensors respectively. Experiment would be needed to find the best number of points to be used in these calculations.

If the process described above is performed by a computer then there is no need to actually do any plotting, since all the positions can be worked out arithmetically, but a graphical display of the corrected track and GPS positions together with local waypoint(s) would be relatively simple once one has got this far and would be much easier to interpret than a position given only in numerical co-ordinates.

For a sailing craft it would be desirable to make some allowance for leeway in determining the dead reckoning fixes. If the system includes a heel sensor then the sail side force can be considered to be a function of the averaged heel angle, the averaging filtering out the effect of waves. The leeway can then be considered to be a velocity component perpendicular to the heading and for simplicity the magnitude of this velocity component could probably be assumed to be proportional to the side force and inversely proportional to the measured boat speed.

7.11 Reading data from equipment which provides an RS232 Interface.

As mentioned in section above, the RS232 interface is a standardised method for interconnecting digital serial signals between equipment, including the connection of computers to peripherals such as mice and printers. Many industrial instruments provide an RS232 connection and some of these instruments could be useful in yacht research. As discussed in Section 7.12 below, instruments specifically intended for marine use often use a form of serial digital interface which is known as NMEA 0183. This is a simple form of RS232 but with the addition of standardised codes which allow the receiving equipment (computer) to recognise data from various types of (mainly) marine instruments.

There are various types of cable connectors in use for RS232 (and NMEA0183 cables). A common type, which is almost universal on the RS232 ports at the back of PC computers, are miniature 'D' connectors with either 25 or 9 pins, and there are standard ways of configuring the cable cores in such connectors. There are ready made 'gender changers' which adapt 'D' type connectors from male to female or vice versa, and there are also ready made adapters which can be used to join between 25 and 9 pin 'D' type connectors. Connectors other than 'D' types are also in use, particularly where there is a requirement for compact cabling or waterproof connections, and these may require study off the manual or seeking advice from the equipment manufacturer in the event that the type of connector on the end of the cable does not match that at the back or your computer. As a last resort it may be necessary to cut the manufacturer's connector off the cable and solder on a 'D' type connector or even to connect the individual wires using something like a screw terminal strip. Again the manufacturer may need to be consulted to determine the pin connections.

The standard cable connector pin-outs for RS232 connection are defined for two categories of connected equipment, data terminal equipment (DTE) and data communications equipment (DCE). Computers are normally DTEs. When an item of DTE equipment is connected to an item of DCE equipment then the standard cable pin-outs should work without modification. When an item of DTE equipment is connected to another item of DTE or an item of DCE is connected to another item of DCE then it is necessary to interchange somewhere along the cable the cores linking pins 2 and 3 (assuming standard pins) these being the transmitted and received data lines. If you are supplied with an instrument manufacturer's RS232 cable complete with connectors at both ends and intended to be plugged into a computer then it is likely that any interchanging of the connections to pins 2 and 3 which may be needed will have been done by the manufacturer when the cable was made up. If this is not the case then there are plug in units which adapt D type connectors to interchange the wiring to these pins.

Let us assume that we have made a satisfactory electrical connection between a device having an RS232 interface, e.g. a scientific measuring instrument, and one of the RS232 ports on a computer. We now want to try sending signals to this instrument (if the instrument is one that can receive as well as transmit) and/or read signals transmitted to our computer by the device. For test purposes this can be achieved initially with a terminal emulation program such as is included with each copy of the Windows™ operating system. Before using this or any other software for transmitting or receiving serial port signals it is necessary to set certain port parameters such as bit rate, number of data bits, number of stop bits, parity if used, together with any 'handshaking' protocol such as 'XON-XOFF'. The transmit/receive software should have features to allow these parameters to be adjusted and the supplier of the communicating equipment should be able to provide the parameter values and advice if necessary.

If it doesn't work first time do not give up too soon, it may be a long job trying different parameters or changing the interconnection of cable connector pins. Once the connection is working properly data can flow and will normally take the form of ASCII characters, including letters, numerals, punctuation marks and 'special' characters. ASCII is the standard method of coding such alphanumeric and punctuation characters into binary numbers which can be transmitted as data bits and it is described in many books on electronics and computers. The manufacturer of the connected instrument will normally have worked out some kind of code by which certain strings of characters can be used to transmit the required information and such details should be given in the instrument manufacturers manual. Many instruments using RS232 will initially require certain sequences of characters to be transmitted to the instrument in order to set up the instrument and initiate the flow of data back from the instrument. Other instruments will send back data as soon as they are switched on. Some instruments will transmit RS232 data in a continuous stream of consecutive readings of some measured quantity, other instruments will wait for a command string from the controlling computer before sending each individual reading. Some instruments can be set up to do either.

As a simple example of RS232 communication, I use an electronic weighing balance which is useful for mixing resin and hardener although it is really too good for such purposes. This balance has an RS232 connection so that if I really wanted to I could record in a computer the weights of all the laminating materials used in a boat building project and see whether the often recommended target of 50:50 resin to glass ratio can be achieved in practice. Two examples of the way this particular instrument communicates with the computer are as follows. If the computer sends the character 'S' followed by a carriage return character to the balance, the balance will respond by waiting until the readings are stable then sending back an 'S' character, followed by space characters followed by numeral characters indicating the weight value followed by a carriage return character. If the computer sends the characters 'S'+'N'+'R' instead of just 'S' then the balance will start sending a series of weight readings rather than just a single reading, but each time it will wait for stability within a tolerance before sending a weight value. A considerable number of other character codes are available, for example to tare the balance, to adjust the stability tolerance, for the balance to send a warning that its levelling screws are not properly adjusted and so on. Even a humble weighing balance can nowadays have quite a number of functions which can controlled or monitored by computer.

If you are writing your own computer program which needs to read RS232 data from the serial port, most high level languages provide a built-in method for doing this, but with some languages there may be problems with missing characters which arrive at the serial port while the computer is busy doing something else. I have purchased from Greymatter Ltd. the ready made source code for a 'chunk' of program which overcomes this kind of problem and also simplifies the setting up of serial port parameters. This code uses an interrupt request to ensure that when a character arrives at the serial port the computer stops whatever it is doing and places this character into memory. The computer then returns to its previous task and continues until it gets to the point when it actually needs the serial port data which it can then read from memory rather than directly from the port. Such source code is available from various software companies and probably also as shareware. A skilled programmer should be able to write such code but why bother if you can download it from the Internet?

7.12 Reading data from NMEA Compatible Equipment

Many electronic instruments sold for use on yachts are provided with an NMEA 0183 interface which allows the measurements to be transmitted to other NMEA compatible instruments or control systems including computers. If one were setting up a data logging system for an experiment on board a yacht which is already equipped with NMEA compatible instruments then one might require to read data from these instruments into the computer, possibly in combination with data from other sources.

The NMEA 0183 standard interface is defined by the US-based National Marine Electronics Association. It is still the only properly defined and widely used standard interface for communication between marine instruments but since this area of technology has advanced in leaps and bounds in recent years the standard is now showing rather serious limitations. It is likely that some new type of standard(s) will be adopted in due course.

NMEA 0183 is a method, or protocol, for serial digital communication, as is RS232. NMEA 0183 is similar to RS232 but there may be minor differences between NMEA 0183 and standard RS232 which I am told could possibly cause damage to the computer RS232 circuits, hence it would be wise to check with the equipment suppliers before making a direct connection between NMEA 0183 signals and a computer RS232 port. In some cases it may be necessary to interpose an NMEA to RS232 converter between the computer and the connected equipment. Such a converter would normally protect the computer by including opto-isolators which allow the signals to pass between the connected items of equipment without a conducting path between equipment. NMEA to RS232 converters typically cost in the region of £30 ($45).

The NMEA 0183 interconnection is by means of a two conductor cable which is the simplest possible cable arrangement, apart from an earth return system, and it is certainly simpler than most RS232 interconnections. The NMEA 0183 interconnection can transmit data in one direction only, from a single data source to one or more receivers, whereas an RS232 interconnection allows bi-directional data transfer. The single data source for an NMEA 0183 interconnection could be a measuring instrument and the receiver(s) could be a computer or other instrument(s) which can make use of the data. If it is required to have multiple sources of data, e.g. a GPS receiver and a speedometer, both sending data to a computer, then this is possible by having each of the NMEA 0183 connections going to a separate RS232 port on the computer. This limits the number of NMEA connected instruments to the number of serial ports (two for many computers, although one of these ports may already be in use for a mouse, printer etc). If more NMEA 0183 connections are required than there are free RS232 ports then it would be possible to either increase the number of ports on the computer by purchasing an adapter card which typically adds four ports, or to use an NMEA multiplex device which is a small box of electronics which receives NMEA signals from a number of sources, say 4 or 8, and then passes them one at a time to a single RS232 port.

Since NMEA 0183 is a unidirectional method of data transmission, a computer connected to a measuring instrument using an NMEA 0183 interface can only receive data, it cannot send instructions to the instrument to start and stop the data flow. Normally the data will start to arrive at the receiving computer once the instrument is switched on, although there could be some switch(s) on the instrument itself to control the flow of data. A terminal emulation program (see section 7.11 above) can be used to examine the data stream for test purposes. The incoming data consists of ASCII characters and it arrives at a maximum rate of 4800 bit/s.

The stream of characters is divided into 'sentences' - groups of characters arranged:

$aabbb,ccc,ccc,ccc,ccc*dd

where:

$ marks the beginning of a sentence

aa are two characters which identify the type of device sending the data, ie. the 'talking device' code. A few examples of talking device codes are:

GP - Global Positioning System (GPS)
DE - Decca
HC - Electronic compass (magnetic field sensing type)
SD - Depth sounder
VW- Velocity sensor (marine speedometer/log)

bbb form a three character sentence format code indicating the meaning and format of the data to follow. A few examples of 'sentence format' codes are:

DBT - Depth below transducer
GLL - Geographic position - latitude and longitude
BWR - Bearing and distance to waypoint (rhumb line)
HDT - Heading - true
MWV - Wind speed and angle
RSA - Rudder angle sensor
VHW - Water speed and heading
VLW - Distance travelled through water (log reading)
VPW - Speed measured parallel to the wind

ccc are data items separated by commas and defined according to the particular format as specified by the sentence format code.

* marks the end of the last data field.

dd is an optional checksum.

The examples given above for talking device and sentence format codes are just a few of many and are for illustration only. There are codes for all kinds of data not all of which are relevant to sailing yachts, for example there are codes for boiler pressure, engine revs etc. Details of the code(s) used by a particular item of equipment would normally be available from the manufacturer of that equipment.

To give one example of decoding a full NMEA sentence, consider the sentence:

$GPGLL,3744.053,N,12225.319,W,182220,A*35

Taking each part of this sentence in turn, the meaning is:

$	Indicates the start of the sentence
GP	Talking device is a GPS
GLL	The data to follow is geographic position in a standardised format defining latitude and longitude and time of fix
3744.053	37 degrees and 44.053 minutes
N	North
12225.319	122 degrees and 25.319 minutes
W	West
182220	time of fix 18:22:20 UTC
A	confirms data is valid (V would mean invalid data)
*	end of last data field
35	this is an (optional) checksum

The sentence ends with a carriage return character

A terminal emulation program can be used for test purposes to save the incoming sentences to a file and print the data, but, to make it worth the trouble and expense of having a computer linked to instruments, specialist software is needed and this will probably enable the computer to process information from more than one instrument and display derived results to provide a more useful and/or easily assimilated display than is possible by studying the small displays on each individual instrument. There are now commercially available programs which do just this and the variety of such programs is increasing very rapidly at the time of writing.

Commercially available software can be very impressive but if you are doing research you are probably trying to do something that no one has ever done before. This means that custom written software, even if it is crude by commercial standards, may actually be more useful than sophisticated commercial programs. Writing a program to read NMEA0183 data will entail reading data from a serial port into a text string variable, as discussed in section 7.11 and then interpreting this text string character by character to get numerical values into variables which can be utilised by the main body of the program. This booklet is not intended to be a tutor on programming, but Section 9 below should give some idea as to what is involved in program writing.

8. ELECTRONIC HARDWARE CONSTRUCTION

Section 7 above includes a number of example circuits for home made signal conditioning. Similar or better circuits can generally be purchased as off the shelf 'black boxes' but the amateur experimenter may prefer to make these circuits from components. If you don't count the cost of your time, it is likely to be cheaper this way and also if you have built equipment yourself you are likely to have a better understanding of its limitations and of how to repair or modify it when this becomes necessary. Maplin Electronics (see Section 11) publish a number of textbooks and booklets on the amateur construction of simple one-off circuits and the subject is also well covered by school text books and hobby magazines available from high street news agents. It is also a subject which is often taught at evening classes run by adult education centres.

Strip board is perhaps the best method for the construction of simple one-off electronic circuits. Strip board is perforated with a grid of holes into which are soldered the connecting pins or leads of electronic components. The strip board has parallel conducting tracks linking these holes in one direction only. By breaking these tracks with a small drill bit or track breaking tool and soldering in perpendicular conducting wires as necessary, it is possible to link up the pins or leads of the components to build the required circuit. The connections into the strip board from remotely mounted components such as power supplies, sensors or a computer interface unit can be made by soldering multi-way sockets or screw terminal headers into the strip board. The screw terminal approach is particularly suitable for experimental work where it may frequently be necessary to alter the connection layout. If you have never built an electronic circuit before, do not expect it to be quick and easy. It takes some time and patience to build even a simple circuit the first time and it only takes one poor solder joint or a strip board track which is not quite fully broken to produce a fault which may take a long time to trace. It helps to work out a rough layout of the components before starting the soldering but it is probably not worth working out the exact layout in advance since this would take so long that one might never get started. It may help to use a larger than necessary piece of strip board and then trim it once the circuit is finished and tested. The essential tools for this kind of circuit construction are an electrician's soldering iron, small wire cutters and pliers, solder 'sucker' (for unsoldering components) and a multimeter with a selection of test probes for fault finding. The total cost of all these is likely to be around £100.

The circuits shown in this booklet include a number of integrated circuits (ICs). OP-amps, regulators, microprocessors and numerous other electronic devices are purchased as ICs which consist of a small rectangular black lump of plastic which encapsulates a tiny piece of silicon, this containing the actual circuit which may be highly complex. An internal inspection of almost any modern electronic gadget will numerous ICs. The connections to each IC are made via rows of metal 'legs' or pins and these pins are numbered in an anticlockwise direction looking on the top of the IC. There is usually a small notch to indicate which is pin 1 and for the dual in line IC which is the type most likely to be used in simple signal conditioning circuits pin 1 is at the left bottom corner when this notch is to the left (see the small diagram attached to fig 12. Circuit diagrams usually show the pin numbers adjacent to the connections to ICs. For mass produced electronics surface mount ICs which have very small close spaced pins are widely used. These pins are for soldering onto the surface of a circuit board rather than being soldered into holes through the board. Surface mount ICs are almost impossible to use in amateur construction so make sure that all ICs purchased are of the traditional type having 2.5mm (0.1") pin spacing. To mount ICs into a circuit board it is often advisable, particularly for experimental work, to first solder an IC socket into the circuit board and then when all soldering is finished to plug the IC into this socket. The use of IC sockets avoids overheating ICs by soldering and also makes it much easier to change ICs if they should be damaged, as can only too easily happen if there are connection errors in a newly built circuit board.

If electronic equipment is for use in a marine environment then protective casings are important. Small items of home built equipment can be housed in watertight boxes which are supplied as general purpose enclosures for use as industrial junction boxes etc. and which are relatively inexpensive. For example, the Radiospares catalogue includes several types of plastic boxes with captive stainless steel screws which hold the lid down onto an O ring seal making the box proof against a jet of water from a hose. One of these boxes say, 120mm square by 90mm deep would cost about £12 ($20) and this size of box would easily be large enough to house home made signal conditioning circuits and batteries for a power supply. Similar boxes without waterproof seals are cheaper and may be suitable if you are confident that the equipment will not get wet.

If you need a large waterproof box to house a complete computer system together with signal conditioning units and other ancillary electronics then I see no reason why such a box should not be built from plywood, glass tape and epoxy resin with access panels and/or display window fixed down onto soft rubber gaskets or onto a large diameter 'O' ring fitted into a groove machined with a router. The access panel(s) may be fixed down with screw fasteners or more conveniently with one of the many types of quick action latches, for example the over centre type, available from companies such as Dxus, Protex and Southco. Such a box could be made large enough to enclose all the ancillary electronics which may be required, including signal conditioning units, power supplies etc. An array of screw terminal connectors could be mounted within the box to allow interconnections between these units. If such a box is truly watertight then a bag of silica gel can be placed inside to keep the humidity low and prevent damage due to condensation. The silica gel needs to be dessicated in an oven before use. However, if the standard of watertightness is at all suspect then silica gel is pointless and it is probably best to make a small drain hole in the bottom of the box so that when the water does get in it can also get out.

If an instrumentation system includes a computer, then it is logical to use the display and controls such as keyboard or mouse which are provided with the computer as the sole 'operator interface' and to minimise the number of switches, knobs and indicator lights fitted to other hardware boxes included in the system. However, one switch will probably be needed just to disconnect the power to conserve the batteries and if the unit is built in a water tight box then this switch also needs to be watertight.

A watertight box containing electronic circuits will usually need cables passing through the walls of the box. One possibility is to fit watertight multipole plugs/ sockets into the walls of the box which is convenient in that it allows the cables to be easily detached from the box, but watertight multipole connectors add to the cost and soldering all the cable cores into them can be a bit tedious. An alternative arrangement is to pass the cables into the box through water tight cable glands fitted into the wall of the box and then to make the connection from cable to circuit boards inside the box using board mounting screw terminals. Water tight cable glands are cheaper than watertight connectors, a typical plastic type for up to 6.5 mm diameter cable being about 60p each.

9. AN INTRODUCTION TO SOFTWARE

The computer will need software in order to take the measurements and to store or present the results. This software can either be written to suit the particular experiment or it can be a commercially available general purpose data acquisition package such as Labview or HP-VEE. Typically, these commercial packages work by allowing the user to specify the intended functioning of some item of equipment, or a whole experimental process, as a block diagram on the computer screen. Such block diagrams can be assembled using the mouse to select different types of blocks from a menu and to arrange them on the screen. For example, one might select a block representing an interface card in the computer and another block representing a chart recorder style screen display. Supposing that a sensor and signal conditioning has been physically wired to the interface card and that the appropriate 'driver' software for the interface card is installed in the computer one can then simply use the mouse to draw a line on the screen connecting these blocks together to indicate that data is to be transferred from the interface card to the chart display. Having done this, a double mouse click on the block representing the chart recorder display would typically cause a 'window' to appear on the screen, this window displaying a scrolling chart of the signal from the connected instrument. On screen buttons and 'scroll bars' would probably appear automatically, these allowing the user to start and stop the chart display, save the results, set up the units of measurement, calibration factors etc. For a complicated experiment where a number of signals from different instruments need to be processed together to produce various results the block diagrams can become quite complicated and setting them up to work properly can be quite time consuming, although generally it is less time consuming than producing the same results by writing software from scratch. However, for an amateur experimenter a commercial data acquisition package of this type may be rather expensive, the software cost being typically £1000 and such packages generally require up to date hardware which will run Windows. An alternative is to use a high level language to produce home made software tailor made for the particular experiment you have in mind. Unless you are a skilled programmer this will not produce the slick looking screen displays and drop down menus of the commercial packages but a compensating advantage is that since you have written the software yourself you may feel that you have a better understanding of exactly how the software is manipulating your data and what to do if something goes wrong. Also, although commercial data acquisition packages are now very sophisticated and cover a huge range of experimental requirements, for complete flexibility in making the computer do exactly what you want there is nothing to beat a purpose written program.

To write programs using a high level language you need a software tool called a compiler. A compiler is a program which reads in the program which you have written and uses it to generate instructions which can be 'understood' by the computer, these instructions being in the form of a file with the .exe extension. An 'integrated development environment' (IDE) is a program, or a set of programs, which includes a compiler together with a set of software 'tools' which assist in writing programs and finding errors in programs.

Compilers and IDEs are available for various computer languages such as Basic, Fortran, C, C++ or Pascal. C++, which is an extension of the original C language, has become about the most popular but all these languages do a similar job and all can be used for writing data acquisition programs. There are numerous textbooks which explain how to use programming languages. Some of the latest IDEs which are produced for professional use, particularly those which are mainly intended for writing Windows programs, are large and complicated software products and a beginner could find the wide range of features confusing. A cut down version may be easier to start with as well as cheaper, or perhaps FOC from the internet.

If one is starting to write software for data acquisition without previous programming experience then the obvious advice is to start with very simple programs. It is probably also best to start with programs which are written to run under the 'DOS' operating system (I am assuming here that we are considering the PC range of computers, not the Apple Macintosh variety) rather than getting involved with graphical user interfaces such as Windows, although having said that there are development environments which are intended to simplify Windows programming, for example Visual Basic, various C based products and Delphi which is based on Pascal.

A really simple data acquisition program could do no more than read data repetitively from an interface unit and write this data onto the screen and onto the computer hard disk. Very little programming is needed to do this since the supplier of the interface unit will almost certainly supply a disk(s) with most of the necessary programme code pre-written in a choice of popular programming languages such as Basic, Pascal and C. I include below an example of such a program written for use with the Minipod 100 parallel port interface unit supplied by Computer Instrumentation Ltd. The Minipod 100 reads up to eight analogue input channels with 12 bit precision. This program is written in Pascal language for the DOS operating system, although Basic or C languages would be equally suitable.

```
PROGRAM MINIPOD;                                                    {1}
{$L MPSUPTP} {$F+}                                                  {2}
uses crt,dos;                                                       {3}
var Add,stat,speed,mode,chan,le,n:integer; outfile:text;            {4}
ch:char;
d:array[0..100] of integer; factor,total:real;                      {5}
procedure POWERCONTROL(var Add,Stat:integer);external;              {6}
procedure MPATOD(var                                                {7}
Add,Speed,Chan,Mode,le,d:integer);external;
```

```
begin                                                       {8}
  Add:= $378; Stat:=1; Speed:=0; Mode:=12; le:=10;          {9}
  powercontrol(Add, Stat);                                  {10}
  assign(outfile,'yacht.dat');                              {11}
  rewrite(outfile);                                         {12}
  clrscr;                                                   {13}
  factor:=1/le;                                             {14}
  repeat                                                    {15}
    repeat until keypressed;                                {16}
    ch:=readkey;                                            {17}
    if ord(ch)=27 then begin close(outfile);halt; end;      {18}
    for chan:=0 to 7 do                                     {19}
    begin                                                   {20}
      total:=0;                                             {21}
      mpatod(Add, Speed, chan, Mode,le,d[0]);               {22}
      for n:=0 to le-1 do total:=total+d[n]*factor;         {23}
      write(total:8:0); write(outfile,total:8:0);           {24}
    end;                                                    {25}
    writeln; writeln(outfile);                              {26}
  until 1=0;                                                {27}
end.                                                        {28}
```

This program has been written to take readings from eight ADC channels and store them on hard disk in a text file called 'yacht.dat'. Each time a keyboard key, other than the escape key, is pressed, readings from each of the eight channels appear on the screen and are also added to the hard disk file. Pressing the escape key ends the program. There is nothing remarkable about this program, the purpose of including it in this article being merely to show that writing programs at this level of complexity is not likely to be particularly time consuming.

To explain the program for the benefit of those who have never tried programming I have included line numbers in curly brackets in the right margin. Pascal should not have line numbers, but these ones will be ignored by the computer since any text in curly brackets (apart from curly brackets starting with {$) is taken to be a note for the programmer's own use and not for the computer. Generally the computer will read the program in the order of the line numbers but there are a number of methods for overriding this when we want to make the computer jump around from one part of the program to another. In this description I refer to the computer as if it were a person. Of course it is nothing of the kind, although it does often seem to behave a bit like a very stupid and obstinate human being. With reference to the line numbers:

line 1 is just a title

line 2 tells the computer to make use of extra information given in the file called MPSUPTP.OBJ. This file was supplied by the manufacturer of the interface unit and making use of this file allows our program to be much shorter and easier to write than would otherwise be the case. It is always a good idea wherever possible to make use of software which has previously been written by either yourself or by someone else. Lines 6 and 7 are also necessary to draw the attention of the computer to certain procedures, i.e. blocks of computer program, which are contained in MPSUOTP.OBJ.

line 3 tells the computer to make use of pre-written program in the 'units' crt and dos. This is pre-written program which is actually part of the Pascal system, you get it included when you buy the development environment. As well as using the units which come with the Pascal system you can also make your own units and fill them with 'chunks' of program which you think may come in handy in the future. When you write new programs you can refer back to these units so as to utilise the chunks of code which you know should already work. This keeps your new program short and simple. Most other modern programming systems have an equivalent to the units in Pascal, for example a similar facility is offered by 'header files' and 'link libraries' in C.

lines 4 and 5 tell the computer that we are going to use certain names, these being Add, Stat etc. to represent certain whole numbers (integers), decimal point numbers (reals), one disk file (text) and one keyboard character (char). These names representing whole numbers, decimal point numbers etc. are called variables. We can set variables to particular values as is done in line 9, and we can use them in calculations and change their values as is done in line 14, where we ask the computer to calculate a reciprocal using the variable 'le' and make the value of the variable 'factor' equal to the result of this calculation.

lines 8 and 28 mark the beginning and end of the part of the program that we are going to write to tell the computer step by step what we want to be done.

Line 9 sets some variables to specific values.

Line 10 'calls', ie. activates, the procedure named 'powercontrol' which is in the file MPSUPTP.OBJ. The computer will now take its instructions from the procedure 'powercontrol', until such time as this procedure tells it to jump back to the original set of instructions. The actual function of procedure 'powercontrol' is to connect a power supply from the computer to the interface unit. Note that this procedure needs to know the numerical values that we gave to variables Add and Stat and so these are 'passed' by including them in the brackets on line 10.

Lines 11 and 12 call the standard procedures which Pascal uses to set up a disk file to be used for text output. The computer will know to look for these procedures in the unit 'dos' referred to in line 3. I have chosen 'yacht.dat' as the name for this disk file and this file will contain the data collected during the planned experiment. Because it will be an ASCII formatted text file it will be possible to read it with any word processor program or with a spreadsheet program such as Excel or Lotus-123.

Line 13 clears the computer screen, ready to display our measurements. The procedure called to do this is 'clrscr', this being a standard Pascal procedure which is in the unit 'crt' referred to in line 3.

Lines 15 and 27 tell the computer to keep on repeating the program in between these lines 'until 1=0'. Since obviously 1 will never be equal to 0 this would be an endless loop, except we have provided another way out of the loop at line 18 - see below.

Line 16 makes the computer repeat nothing at all until someone presses one of the keys on the keyboard. This is just a way of making the computer wait until the operator takes some action.

Lines 17 and 18 find out which of the many keys the human being has chosen to press, and if it happens to be the key with ASCII code 27 (this is the escape key at the top left of the keyboard) then the computer will save the data and then 'halt', i.e. stop the program.

Line 19 tells the computer to repeat the instructions between the next 'begin' and 'end', i.e. between lines 20 and 25, using a new value for the variable 'chan' each time round. Chan starts as 0 the first time round, and ends up as 7 the last time round. The value of 'chan' is 'passed' to the subroutine MPATOD each time. MPATOD is a pre-written procedure from the file MPSUPTP.OBJ and it is this procedure which actually takes the readings from the interface unit. Each time it does this it needs to know the value of 'chan' to know which of the eight analogue channels to read and a value of 'le' which is the number of readings to take in quick succession. It also needs a value for mode, this indicates whether to use bipolar or unipolar input and whether to use single ended or differential mode. In this program mode is given a value of 12 (line 9) which means that the input range is unipolar (0 to 5volts) and the channels are single ended, meaning that there are a full 8 channels each measuring an input voltage relative to ground level. Different values for mode set alternative options. If differential mode had been specified this would mean that there would be effectively only 4 input channels but that each of these would have a pair of input lines and the computer would record the difference in voltage between the two lines in each pair, irrespective of the values of the voltages relative to ground. The procedure MPATOD places ten readings of the required channel in 'd', which is not a single variable but a group, or array, of up to 100 as specified in line 5. The idea of taking 10 readings, not just one, is that this allows groups of readings to be averaged to even out any small fluctuations. If we had wanted 20 readings to be taken and averaged rather than 10 then we would simply have set the value of Le to 20 in line 9, a very simple change.

Line 23 calculates the average of the 10 readings, the result going into the variable total.

Line 24 writes the average reading both to the disk file and the screen. Since this line is within the repeating loop between the begin and end in lines 20 and 25, it gets repeated once for each of the eight channels. This places a neat line of readings on both the screen and the disk file, then the 'writeln' statements in line 27 generate 'carriage returns' to jump down to the next screen line and file position ready for the next round of readings.

Since the Minipod 100 provides 12 bit precision the readings will be numbers in the range 0 to 2^{12}-1, ie. 0 to 4095. The next improvement one might want to make to this simple program is to add/subtract a zero value (offset) to the reading from each channel then multiply by a gain factor so as to produce numerical output in units according to the measured parameters. The values for the offset and gain factors will generally need to be determined by a calibration process.

The above description is a little laborious for such a short programme, but I hope that it will give the uninitiated an idea as to how computer programs are written. The text of the program is typed into the Pascal IDE in much the same way that a letter would be typed into a word processor program. The IDE is then set to compile the program which converts it into an .exe file and then to run the program which allows the program to be tested whilst still in the IDE. If there are mistakes in writing the program, the IDE will place messages on the screen which, if you are lucky, will give you at least some clue as to where you have gone wrong. In final use, the program in the form of an .exe file would probably be run from the operating system rather than from the Pascal IDE. Running this small program from the operating system is done in just the same way that you would run any large professionally written program such as a word processor or spreadsheet.

This 'MINIPOD' program is about as short a program as you are ever likely to use in data acquisition work. Although it is short, it is potentially quite useful and is the kind of program which comes in handy when you need to record some important experiment and your more complex software fails because of a bug which you have no time to trace. Once the experiment is completed and the data is safely stored on the hard disk then it can be analysed at leisure either using any spreadsheet program or using further purpose written software. This is the easiest way to get started and for experiments which are conducted afloat it has the advantage that as much of the work as possible is done in a dry environment after the experiment is completed. However, there are also advantages in analysing the data and displaying the results as the experiment proceeds. This will tend to require more detailed advance planning and more complex software will need to be produced before starting the experiment.

With a certain amount of programming experience it is quite possible for such software to display the results of an experiment as a set of graphs which appear on the screen either immediately after a set of readings has been taken or as the readings are actually varying, this being known as real time processing. Just as an example of the kind of effect which should be quite feasible, one could write a programme which could take readings from sensors as a yacht is sailed on various courses under varying conditions and use these readings to automatically plot polar co-ordinate graphs of boat speed vs. true wind direction for various ranges of true wind speed. The polar plots could appear on screen with a cursor showing the current performance and for windward courses this would make it immediately obvious whether or not the current vmg is close to the optimum. If such a program were allowed to run for long periods it could build up a detailed picture of the yacht's averaged historical performance under a wide range of conditions and current performance could then be visually compared with this historical record.

It is frequently necessary to damp readings from instruments to obtain useful readings. For example, if a car petrol tank contents gauge were not heavily damped the needle would be all over the dial as the petrol sloshes about in the tank and it would be almost impossible to judge the contents. Sensors and signal conditioning circuits often include electronic or even mechanical hardware for damping, for example the circuit shown in Figure 12 includes a resistor and capacitor for this purpose. With a computer data acquisition system it is possible to supplement any hardware damping built into the instrument or the signal conditioning with software damping, referred to as low pass numerical filtering. Consider a program which is reading in a stream of data from a sensor measuring, say wind angle, and plotting this data on a moving chart display on the computer screen. If the program plots every one of the measured points then the plotted angle will be jumping up and down by at least a few degrees as a result of short term turbulence. This may be useful if we are studying the turbulence, but if we want to monitor longer term wind shifts then we should plot not the individual readings but the average of say the last thousand, or the last hundred thousand, or whatever, readings recorded. This is an example of a numerical low pass filter and it is quite easy to build into software. The effect is to produce a steadier plot but there is also a loss of information about short term changes - one cannot have it both ways. It may be a good idea to write the program so that the operator can select the number of readings to be included in the averaging calculations, so as to give adjustable damping to suit requirements.

Structured programming is the key to writing large programs without getting in a hopeless muddle. Structured programming is a range of techniques which are used to build up large programs from smaller and more easily managed sections which can be individually developed and tested. In Pascal, these small sections of code could be 'Procedures', the equivalent in Basic or Fortran is called a 'Subroutine', in C a 'function'. The above example program makes use of a couple of Pascal procedures which were written by the supplier of an interface unit and in this case these procedures are used without even having access to the Pascal coding which was used to create them. Once such procedures have been written and properly tested they can be used to form a part of any number of future programs, saving much re-writing and re-testing.

'Object Oriented Programming' is a further advance in structured programming and makes use of 'Objects' as well as 'Procedures'. Objects combine sections of code with the data which needs to be used with that code, so forming packages of code and data which are particularly easy to use as modules in building up large programs. Often it is convenient to make an 'object' in a software program correspond to a particular real world object. For, example we might have a software 'object' which is written to represent an actual electronic log in the real world. This software 'object' could be provided with facilities which, for example, might allow the program using it to make it appear on the computer display a dial looking like a speedometer and odometer, to obtain from it values for speed and distance which can be used elsewhere in the program (these would of course be real values taken from the real world instrument via. an interface unit), or perhaps even to carry out a calibration operation. The idea is that once you have made such a software 'object' work properly you never again need to think about how it works, you just use it as it stands to provide a useful function in one or more larger programs. The same should be true of the real world instrument, once it has been properly manufactured and tested you hope you never need to take it apart.

There are software companies which sell, or sometimes even give away, 'chunks of code' which you can build into your own programs so that you can add sophisticated features with relatively little effort. These may be provided either as sections of ready written source code which you can compile with your own source code or they may be pre-compiled object code or dynamic link libraries which link with your compiled program without your needing access to underlying source code. Quin Curtis and other companies offer such software 'libraries' which can, for example, enhance your data aquisition software with professional looking graphics or add complicated mathematical data processing functions. If you buy commercial data acquisition software such as HP-VEE then you get with it software libraries which will allow you to build some of the features of HP-VEE into your own programs, or alternatively you can also build sections of your own code into HP-VEE. This is all part of the trend towards 'modular' software which can be juggled around and fitted together in different ways to suit different applications.

There is great scope for individual expression in producing computer programs, the only danger being that program writing can easily become an end in itself so that one looses track of the original objective which was presumably to complete the experiment and publish the results in an AYRS publication.

10. ELECTRONIC CHART PLOTTING

Much of the recent commercial interest in marine computer hardware and software is centred on electronic chart plotting, this being the use of an electronic system to store the geographical data represented on paper charts and to use this data to display a chart on screen. The next step is to link electronic charts to electronic position finding systems such as GPS so that a yacht's position can be shown by a cursor superimposed on a chart display. This is a development which must make traditional navigation skills redundant, or at least means that in future such skills will be only for the traditionalist. The problem of navigation is no longer knowing where you are but is simply deciding where you would like to go. I wonder how the navigation evening class 'industry' will survive this revolution, perhaps these classes will continue to be popular but mainly for social reasons! It has often been argued that traditional navigation skills should be retained as a backup in case of instrument or power failure but since one can now buy two or more backup GPS systems plus numerous spare batteries for the price of a good sextant even this argument is looking a bit weak, after all a sextant could also fail if it suffers a bad knock.

The use of computers for electronic chart plotting is outside the main scope of this booklet but a brief discussion may be appropriate since it is a subject likely to be of interest to anyone who uses both a yacht and a computer.

Electronic chart plotters are available as dedicated stand-alone systems or alternatively software is available that will enable a general purpose computer to perform as a chart plotter. The dedicated systems are in effect computers which are dedicated to just this single application and are not suitable for general purpose use. They usually work from a yacht's power supply and are at least weather resistant. They tend to have rather small and poor quality displays compared to a typical general purpose computer.

If you already own a computer and GPS, you can in principle have a superb chart plotter system without further hardware expense other than possibly needing an NMEA to RS232 converter. The quality of the chart display is likely to be better than all but the most expensive dedicated chart plotters and since the system includes a general purpose computer it can be used to do more than just chart plotting, even office work if you are a home (yacht) based office worker or salesman. Since weatherproofed general purpose computers are now becoming available this is an attractive approach to electronic chart plotting although a waterproof computer for marine use is considerably more expensive than a budget priced dedicated chart plotter. A disadvantage of dedicated chart plotters is that they are generally designed to work with just one type of electronic chart, with chart plotting software which is permanently installed in the unit and which may not be easy to update. This means that they may not be able to take advantage of the improvements in the digital storage formats for electronic charts which will almost certainly come about during the next few years.

It is hardly worth listing the chart plotting programs which are commercially available today since such a list could be out of date within a month. Chart plotting software could include features as listed below, although I doubt whether any programme yet includes all these features:

- Real time true position display from GPS or alternative sources, e.g. DECCA
- Automatic 'panning' of the chart display so that the screen remains centred on the area around the yacht.
- User choice of information to be displayed on the chart so as reduce clutter.
- Display of instrument readings, e.g. depth, wind and performance data, engine data.
- Prediction and display of tidal data and calculation of effect on performance.
- Automated plotting of position using traditional navigation methods including dead reckoning, compass bearings and transits. Also automated calculation and plotting of position from sextant observations.
- Input of waypoints to define the route of a voyage.
- Link to autopilot for automatic route following.
- Prediction of ETA at waypoints.
- Display of weatherfax messages.
- Text and pictures, maybe even video, detailing local ports and places of interest, i.e. an electronic pilot book/tourist guide.
- Automatic update and printing of a log book which can be edited using a word processor to make a holiday record - presumably including holiday snaps taken with a digital camera!
- Superimposing radar targets on the chart display.
- Immediate updating of the chart library using an update disk or other data transfer medium, including the Internet.

The present limitation on such developments is that the suppliers of digital charts are understandably doing all they can to avoid making their data available at low cost or in a manner which allows the data to be copied for the benefit of people who have not paid for it. Digital charts still seem to cost more than paper ones but there is at least a possibility that the prices will drop as a result of commercial competition and/or software piracy. If this happens it might eventually be possible to acquire all the world's charts, land maps, pilot books and travel guides on a few CD-ROM discs, or some other data storage medium. The actual manufacturing cost of such a set of disks is perhaps a few pounds. Wonderful for armchair sailors who could spend the evening browsing through charts of places they would never sail to, but if no one makes much turnover by selling charts, would the charts get properly updated and would any hydrographic organisations survive other than for defence purposes?

Another effect of cheaper and more widely used digital charts could be the elimination of purpose made chart tables on yachts. Today, any yacht manufacturer which fails to provide a suitably impressive chart table surrounded by an array of instruments will receive damning criticism from the boat reviews in the yachting press. If it is accepted that the chart together with all the data from the instruments can be better displayed on a robust computer monitor built into a bulkhead, or mobile for use around the yacht, will we still insist on a chart table on a small yacht? Perhaps the space it takes up could be used for a proper locker for storing and drying foul weather clothing.

To overcome the relatively high prices currently charged for electronic charts, perhaps the amateur computer enthusiast might consider producing home made versions. Scanning of commercial paper charts into a computer would be illegal and in any case you would still have to pay for the paper charts unless you can borrow them. However, does an electronic chart really need to be as detailed as a paper chart? Detail adds interest to any chart, paper or electronic, but it could be argued that a large proportion of the detail shown on paper charts is only essential to help the navigator determine position and so is not strictly necessary if position is to be electronically determined and plotted. If one accepts this argument then perhaps the absolute minimum information required on an electronic chart is nothing more than the intended waypoints together with an indication of areas of shallow water, dry land or other danger. This information could possibly be scanned, or otherwise input, from non-copyright sources and displayed using a simple 'home-written' graphics program which also inputs and displays GPS position and sounds a loud warning if one strays too near a danger area. I hesitate to suggest this since it is obviously a second best alternative to proper electronic chart plotting and perhaps it should only be considered as a means of providing a last resort warning should the navigator be negligent. Single-handed and short-handed sailors do occasionally get shipwrecked by colliding with land masses whilst asleep, and a simple system of this kind could at least provide an audible warning when the yacht comes within, say 5 miles of any coastline or off-lying danger. The alarm on an echo sounder can perform a similar function but will probably give a later warning.

11. EQUIPMENT SUPPLIERS

Listed below are a selection of companies which supply equipment which may be of use to AYRS members carrying out the kind of experimental work described in this booklet. This list of suppliers is necessarily short and I am sure that there are many other suppliers which could be mentioned.

Note: These companies are for the most part UK-based. Similar companies exist in other countries, but it has not been possible to research and list them here.

Suppliers of electronic components:

Three companies which act as retailers for the supply of a wide range of components for use in building electronic equipment are:

Farnell Electronic Components Ltd. Canal Rd. Leeds, LS12 2TU, Tel. 0113 263 6311.

Maplin Electronics, PO Box 3, Rayleigh, Essex, SS6 8LR. Tel. 01702 554155 Fax. 01702 553935.

Radiospares Components Ltd. PO Box 99, Corby, Northants. NN17 9RS Tel. 01536 201234

Of these three companies, Maplin Electronics is the most likely to be of interest since it is the only one which specialises in serving the amateur enthusiast. Radiospares and Farnell serve mainly industry, although Radiospares has twelve offices around the country and these are open to the general public as well as to trade customers. The range of components stocked by Maplin Electronics is large enough to meet most requirements in yacht research, although it is a smaller than the huge range stocked by the other two companies. The range stocked by Radiospares now extends well beyond electronics since it includes items from metal working tools to office furniture and many other areas. Maplin Electronics sells components both by mail order and through their high street stores located in a number of towns around the UK. The Maplin catalogue is available from WH Smiths whereas the Radiospares and Farnell catalogues are not nearly so easily obtainable.

Suppliers of 'ruggedised' and marine computers and displays.

There is little point in listing suppliers of general purpose desktop and portable computers since there seem to be dozens of these suppliers all selling a similar range of products and they advertise extensively in computer magazines. The lowest prices tend to be from manufacturers who sell direct rather than from high street retailers. As discussed above, general purpose computers may well be useful in yacht research but for long term installation in a marine environment it may be worthwhile considering a ruggedised computer, or one designed specially for yachts, as supplied by the following companies:

Aqualogic Ltd. 15-16 Marlow Drive, St. Catherines Hill, Christchurch, Dorset, BH23 2RR. Tel 01202 486550 01202 486311

Datalux International Ltd. 11 Pelham Court, Broadfield, Crawley, West Sussex, RH11 9SH. Tel 01293 540092 Fax 01293 540094

Fahrion Electronic An den Kiesgruben 18, D-73240, Wendlingen, Germany. Tel 49 70242096 Fax 49 702453791

Fieldworks - distributed by Amplicon Liveline - see below.

Panasonic Business Systems UK Ltd. Willoughby Road, Bracknell, Berks. RG12 8FP Tel. 01344 853598

Softwave Ltd 4 Aranmor House, Kington Hill, Kingston, KT2 7LY. Tel. 0181 549 0650 Fax 0181 546 1090

Wavelength Marine Ltd. Unit D2, Fareham Heights, Standard Way, Fareham, Hants. PO16 8XT Tel. 01329 827527 Fax 01329 827823.

Suppliers of Interface units for computer data acquisition.

Adept Scientific PLC 6 Business Centre West, Avenue 1, Letchworth, Herts. SG6 2HB Tel. 01462 480055 Fax 01462 480213

Amplicon Liveline Ltd. Centenary Industrial Estate, Hollingdean Rd. Brighton, East Sussex BN2 4AW Tel. 0800 525335 Fax 01273 570215

Computer Instrumentation Ltd. Building 3, Woods Way, Goring on Sea, West Sussex. BN12 4QY Tel 01903 765225 Fax. 01903 765547

National Instruments 21 Kingfisher Court, Hambridge Rd., Newbury, Berks. RG14 5SJ Tel 01635 523545 fax 01635 523154

Pico Technology Ltd. Broadway House, 149-151 St Neots Rd. Hardwick, Cambridge. CB3 7QJ. Tel 01954 211716 fax 01954 211880

Miscellaneous Items

Hot wire anemometers: Prosser Scientific Instrument Ltd., Lady Lane Industrial Estate, Hadleigh, Ipswich, Suffolk, UK. Tel 01473 823005 Fax 01423 824095

Load sensing clevis pins (Strainsert) Variohm, Williams Barns, Towcester, NN12 6HP Tel. 01327 351004 Fax. 01327 353564

Magnetic field sensor (for building electronic compass): Speake & Co. Ltd., Elvicta Estate Crickhowell, Powys, NP8 1DF Tel. 01873 811281 Fax 01873 810958

NMEA183 to RS232 converters: Try the suppliers of marine computers as above or of chart plotting software, as advertised in the yachting press.

Sensors for boat and wind speed: Autonic Instruments Ltd. Woodrolf Rd. Tollesbury, Essex, CM9 8SE Tel 01621 869460 Fax 01621 868815

Software: Greymatter Ltd., Prigg Meadow, Ashburton, Devon, TQ13 7DF. Tel. 01364 654100 Fax. 01364 654200

Tilt/heel sensor: Lucas Control Systems, (Shaevitz Accustar Sensors), 543 Ipswich Road, Slough, Berks, SL1 4EG. Tel. 01753 537622 Fax. 01753 823563.

12. BIBLIOGRAPHY

1. Chisnell on Instrument Techniques - Chisnell M. - Waterline Books - This short book discusses techniques for making the best use of conventional sailing instruments in yacht racing. Includes sections on calibration and polar performance graphs. Does not give detailed information on computer based instrument systems.

2. The Bernard Babani range of books - Various authors - Bernard Babani (Publishing) Ltd., The Grampians, Shepherds Bush Road, London W6 7NF UK. This is a series of over 100 small books on electronics and computers priced from about £1 to about £6 and written principally for amateurs. An full list of titles can be obtained by writing to the publisher with a SAE. One of these books, 'Easy PC Interfacing' by R A Penfold (reference BP385 in the series) covers the DIY construction of a parallel port interface unit for data acquisition. Another, reference BP 272, covers the construction of an internal ISA interface card for a desktop PC. A number of the other titles would be useful to a novice attempting data acquisition work.

3. The Art of Electronics - Horowitz and Hill - Cambridge University Press - Classic reference work covering the entire field of electronics at a medium level of detail. Not particularly intended for amateurs but more readable than one might expect for this kind of textbook.

4. AYRS publication No 119. Includes articles on:

   A data logger and its use to record performance (G. Chapman),

   A wind direction sensor (G. Chapman)

   A marine electronic log adapted from a bicycle speedometer (Bob Spagnoletti)

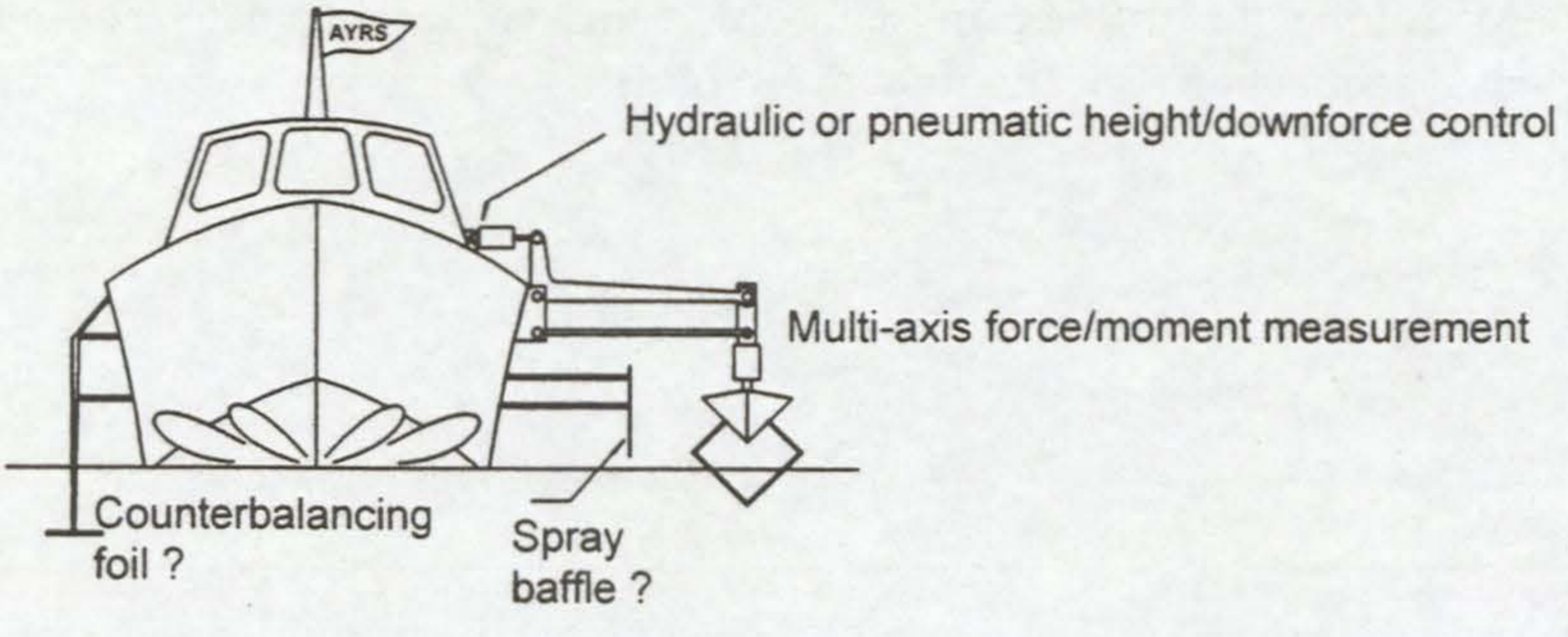
   Timing at speedweek (Robert Downhill)

   Measuring the stiffness of sailboards using an accelerometer and computer data acquisition (B Cartwright & G Ward)

COMPUTERS AFLOAT

An Introduction to Data Acquisition for Yacht Research

Contents:



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