CHAPTER 14

IMPROVEMENTS IN THE ELECTRIC STEP GAUGE FOR MEASURING WAVE HEIGHTS

C.M. Verhagen
Technical Physics Department
T.N.O. and T.H.
Delft, Holland

SUMMARY

Continuous systems are compared with a step system. The influences of parasitic series and coupling resistances are examined.
Methods of decreasing these parasitic resistances are considered. Relays are being used to eliminate the errors of these effects. When no relays are used a decrease in the effect of the parasitic resistances is obtained by switching in condensers or inductors instead of resistors in an LC system as part of an oscillator circuit. Some considerations on design are given.

1.1. In fulfilment of the Dutch Rijkswaterstaat our Laboratory is engaged in the development of an electrical system for measuring wave heights.

1.2. An electrical system was preferred to a mechanical one because the latter was expected to have a much shorter life.

CONTINUOUS SYSTEM.

2.1. Some types of continuous electrical wave gauges are: a resistance type consisting of a double metal wire placed vertically in the sea, the resistance between the wires producing a straight-line decrease when plotted against the water height. A capacitive type is obtained by placing an insulated wire vertically in the sea, the capacity increasing in a straight line when plotted against water height. Another electric gauge is the inductive type in the form of a long, thin coil (delay line without screening) placed vertically in the sea. The result is changing impedance because of the "secondary" charge produced by the conducting seawater.

ERRORS DUE TO PARASITIC EFFECTS.

2.2. In the resistance type, corrosion or fouling of the wires will result in an unknown increase in the shorting resistance. The same happens if the salinity of the water changes (estuaries).
The same sort of calibration change appears in the capacitive type in which any fouling affecting the insulating material will change its capacity. Because the inductive type generates current in a "thick" water layer such

fouling is of less consequence, but changing salinity will result in large errors which are difficult to compensate for if the salinity changes at different depths.
A second type of error applying to all these continuous systems is the effect of the film of water remaining after the passage of a wave.

ADVANTAGES OF THE STEP SYSTEM.

Because of these errors a step system was chosen instead. For a continuous system the total error is the sum of all the small errors caused by the film of water remaining and changing surface conditions. A step system, however, can be furnished with a threshold high enough to suppress the effects of parasitic coupling between "wet" electrodes above the surface of the sea and low enough to take the highest electrode series resistance into account, supposing that the first effect is smaller than the second. In that case though the total error may be much larger than the threshold value no error will appear.

PARASITIC EFFECTS IN THE STEP SYSTEM.

A series resistance does arise because of the limited conductivity of seawater. For a spherical form of electrode with a diameter of 1 cm and a conductivity of 4.4 $ohm^{-1}m^{-1}$ the resistance will be 3.6 ohm; in estuaries, where the system should also work in relatively fresh water (4.4×10^{-2} ohm^{-1} m^{-1}) this will increase to some 400 ohms.
The series resistance will be further increased as a result of the resistance near the electrode surface caused by fouling and electrochemical action. Both effects decrease if the frequency of the electric current applied is raised. Owing to electrolytical action corrosion of the electrodes will take place except if spectrographically pure carbon is used.

Concerning the parasitic coupling between electrodes caused by the remaining film of water we have found by calculation that the water film resistance between the electrodes and earth is of much greater consequence than the resistance between successive electrodes.
Any earthed metal construction parts giving rise to a water film coupling with the electrodes should therefore be carefully avoided.

The resistance between successive electrodes will be increased if the electrodes are mounted on thin wires. In this way a water film of small cross-section is obtained, giving rise to a relatively high coupling resistance. We

have achieved this by mounting the electrodes on hard drawn copper wires insulated with black polythene. The wires are bunched together with nylon cord. Each wire with its terminal electrode is bent at right angles to the bunch. This assembly is attached to a support in the sea. This idea was first used in Indonesia by engineers of the B.P.M.
The cable surface should be smooth, so as to ensure minimum water adherence.

RESISTANCE STEP GAUGE.

Our first experience with step gauges was gained with the well-known parallel resistance type. In this gauge resistances are connected in parallel by the seawater-electrode "switches". The resistance then decreases as a straight line when plotted against water height. When an electrical potential is applied to this resistance a current will flow that increases in a straight line when plotted against water height.
If in such a system the resistances have a value R and the parasitic series resistance a value R/100 the indicated height will be 1% too low or one step if a total of 100 electrodes is used.
If for this system the electrodes above water level are wet and coupled by means of a water film resulting in a resistance between two successive electrodes of R/2 the system will indicate one step too high.

If this is the maximum allowable error the given example shows that for the resistance parallel type of gauge a ratio of 50 between coupling and series resistance should not be exceeded.
In our estuaries it was feared that this ratio would be much smaller.

THE RELAY STEP GAUGE.

For the reasons given above a threshold should be introduced. To achieve this the sea-electrode switches should operate through relays. By setting these relays sharply to operate at the maximum expected series resistance an ideal on-off system was produced by a group of Dutch Rijkswaterstaat workers.
Relays with as narrow an on-off current ratio as possible should be selected for this purpose. The use of relays however introduces a partly mechanical element resulting in a short life because of the high switching rate.
The relays should therefore be easily accessible, making an expensive multicore cable necessary.

THE CONDENSER STEP GAUGE.

To reduce the error from the parasitic resistances we have in our design made use of the 90 degrees phase

shift between the voltages across either a condenser or an inductance on the one hand and a series resistance on the other. Because of this phase shift the impedance of the condenser (inductance) will increase only by the square of the ratio between the impedance and the parasitic series resistance instead of in a straight line when resistances are used.
If a series resistance of say ten percent is introduced the impedance will only increase with 1%.

Condensers are preferable because of the ease which with they can be combined to make any value. They are also very easily obtainable.

Together with this switched condenser system where the capacity changes with the water height an electrical circuit should be found that translates this capacity change into a quantity that is easily transmitted by cable or by ratio transmitter if a cable cannot be used.
We have decided on a frequency modulated system. In this system the changing capacity is converted into a changing frequency. At the receiving point this changing frequency can easily be converted into a changing voltage. The advantage of this is that this conversion is independent of the amplitude of the voltage the frequency of which is to be measured. This is of great importance because unpredictable attenuation of the transmitted voltage easily occurs.

The translation of the capacity change into a frequency change is done by including this capacity in the tuned part of an oscillator.
For an RC oscillator two gauges are necessary; for an LC oscillator only a single gauge is needed.
The frequency of an LC oscillator is expressed as:

$$\omega = 2\pi f = \frac{1}{\sqrt{LC}}$$

The capacity in the LC circuit (fig.1) is for example made up of 100 condensers one pole of each being connected to a common line, the other poles being connected to the electrodes. Condenser values are chosen making a capacity of:

$$C_h = \frac{C_{min}}{(1-\frac{2}{3}\frac{h}{H})^2}$$

in which h = waterlevel and H = highest electrode level

The frequency decreases as a straight line when plotted against water level. The ratio of the condenser C_{min} and the switched condensers establishes the frequency range, for which 500 c/s to 1500 c/s has been decided on.

For this system (with 100 electrodes), if all the electrodes are submerged and a parasitic series resistance with a value of $\frac{7}{\omega_{max}C_{min}}$ appears for each electrode calculated is found to be equivalent to one step too low.
If for the same system with all the electrodes out of the water, each electrode is coupled to its neighbour by resistance of $\frac{35}{\omega_{max}C_{min}}$ the resulting error is equivalent to one step too high.
This example, in which the series resistance has a value of 1/5 th of the parasitic coupling resistance, shows that a situation has been created which only relays can cope with. If we compare this with the system in which a chain of resistances is employed and in which an error of one step were to appear for a ratio of 50 between the parasitic coupling resistance and the series resistance, we see a tenfold improvement.

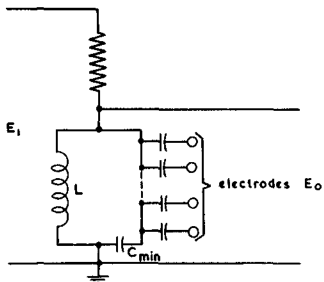

Fig. 1

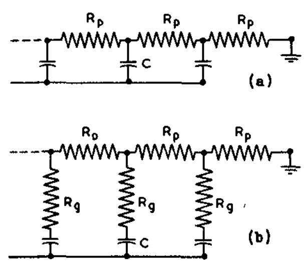

Fig. 2

THE EFFECT OF WIRE MOUNTED ELECTRODES.

In the above mentioned case in which we presume the parasitic coupling resistance of $R_p = \frac{35}{\omega_{max}C_{min}}$ only the effect of coupling along the cable between two adjacent electrodes is considered (see fig. 2a). By mounting the electrodes on projecting wires each electrode is coupled to the cable through an individual resistance (Rg) caused by the waterfilm on this wire (see fig. 2b).

In this case a lower value of Rp might appear for the same error.
If for example Rg = 10 Rp the value of Rp for an error of one step is found to be:

$$Rp = \frac{8}{\omega_{max}C_{min}}$$

The same thing applies to the parallel resistance gauge mentioned earlier, in which an error of one step arises for Rp = R/2 in the situation shown in fig. 2a.
With the electrodes on projecting wires and Rg = 10 Rp we find:

$$Rp \geqslant \frac{R}{4.3}$$

if the error is to be kept down to one step or less.

The use of frequencies between 500 and 1500 c/s makes the series resistance caused by fouling and polarisation of the electrodes negligible compared to the few hundred ohms we anticipate in estuaries.

A GAUGE WITH RADIO TRANSMISSION AS ALREADY CONSTRUCTED.

To predict wave heights near the construction pit for the sluices to be built in the mouth of the Haringvliet, waves are being measured well to seaward.
As a cable was considered unreliable wireless transmission was decided upon.

Following the design considerations given above, a system was built and is now working consisting of a double condenser step gauge together with an RC oscillator. Though we would now prefer an LC system enabling a single electrode system to be used, this idea only occurred to us after the construction of this gauge was completed. The gauges operate over a range of 7.5 meter and both gauges have 50 electrodes. The relative height of the two gauges is such that the electrodes of the one are just between the electrodes of the other, hence the frequency is changed every 7.5 cm.

Because electric coupling between the two electrode systems could not be tolerated the two electrode systems are some distance away from each other.

By designing the oscillator carefully the frequency to water height relation is a straight line within 1%. The signal is transmitted by a small crystal-controlled 170 Mc/s transmitter having an output of 0.2 Watts. The signal is received 5 km away on a Yagi 10 element aerial. The modulation signal is fed to a Hewlett Packard frequency meter model 500 B. A feature of this meter is its scale spread of three or ten times which facilitates reading the waves. The frequency meter output can also be recorded.
The modulation frequency range of 500 c/s to 1500 c/s makes transmission over telephone lines possible.

The power consumption of the transmitter is 4.6 Watts. The high tension voltage is obtained from a specially designed transistor oscillator.
The five Leclanché elements of 1.3 Volt and 2000 Ah require renewal once every two months.

The influence of the parasitic series and coupling resistances in this gauge depends greatly on the difference between these resistances in both electrode systems and is therefore difficult to estimate.
Supposing a difference of 20% we find for errors of one step or less:

$$R_p \geqslant \frac{p}{15} r$$ where p is the number of parasitically coupled electrodes.