DETECTION OF LEAKS IN STEAM LINES BY DISTRIBUTED FIBRE-OPTIC TEMPERATURE SENSING (DTS)

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ABSTRACT

This paper describes an instrumentation system concept which should be capable of early detection of a leak-before-break in main steam lines.

Distributed fibre-optic Temperature Sensing (DTS) systems have been used in commercial application for a few years now, but in other industries and applications. DTS uses very long fibre optical cable both as a temperature sensor and as a means of bringing the information back from the sensor to the terminal equipment. The entire length of the fibre is sensitive to temperature and each resolvable section of fibre is equivalent to a point sensor.

A typical application comprises 4km of fibre optical cable, in which the average temperature of every metre is measured as a temperature "point" to an accuracy of one degree C in a measurement time of 20 seconds. The fibre optic cable is measured at both ends, so that signals are not interrupted if there is a break in the cable. Breaks in the cable would be alarmed to the operator.

This commercially available DTS system could be adapted to indicate leaks in steam lines. The fibre-optic cable could either be run either just underneath the aluminium sheathing covering the insulation over a steam line, or between the two layers of insulation. This would detect an increase in the temperature of the insulation due to a steam leak.

For example, a fibre optic cable could be wound around a steam line with the cable turns spaced at 0.25m. For a steam line of 2.5 metre in circumference, there would be 10 temperature "points" per metre of pipe which should provide adequate coverage for detecting a local increase in temperature of the insulation due to a steam leak.

In the above arrangement, a 4km fibre optic cable could monitor a total length of 300 metres of steam lines, allowing 100m for connections back to the DTS terminal equipment.

Because the temperature of the insulation is not very high, a commercial grade plastic covered fibre optic cable might be suitable, although cables in flexible stainless steel tubing are also available.

A test rig is being set up in Canada to test the above concept, and to determine the minimum spacing required between the turns of fibre optic cable required to achieve an adequate response time.

1. REQUIREMENT

It has become a requirement in the design and operation of nuclear power stations to consider the possibility of a guillotine failure of a main steam line and the effect of consequent pipe whip, pressure surge or the effects of steam on safety related equipment, the main control room and operators. In some stations, blow out panels have been added to the turbine building and adjacent rooms containing safety related equipment have had walls and doors strengthen. In the design of new stations, these requirements can be largely accommodated in an improved layout where interlocked steam proof double doors will prevent steam getting into safety related equipment and areas.

However there is the argument that a guillotine failure of a well designed steam line would be proceeded by a leak-before-break. Such steam leaks could be detected by very frequent visual inspection but this may be difficult because of the length and location of the steam lines. Therefore a practical, reliable and easy to interpret instrumentation system to detect such steam leaks has been sought.

2. TECHNICAL CONCEPT

Distributed fibre-optic Temperature Sensing (DTS) systems have been used in commercial application for a few years now, but mostly in other industries and applications [1].

In the DTS system, a single optical fibre is used both as a temperature sensor and as a means of bringing the information back from the sensor to the terminal equipment. The entire length of the fibre is sensitive to temperature and each resolvable section of fibre (typically 1m long) is equivalent to a point sensor. A laser signal is sent into one end. Reflections occur all along the cable and are returned to the sending end where these reflected signals are measured. The distance along the cable of these reflections is detected, and the return signal from each point is proportional to the temperature at that distant point.

The terminal equipment which comprises an Opto-electronic unit with built in data processing with out put to a PC video display.

It is not the purpose of this paper to describe this DTS technology; details may be obtained from the inventors and suppliers of the equipment, but rather to describe a concept for the application of a DTS system to detect leaks in main steam lines.

3. RECENT APPLICATION OF DTS.

A recent application of DTS has 4km of optical fibre providing 3000 temperature points measured every two minutes, with only four fibres back to a single scanning system. Reference [1], (page 116 (a) Process plant through to top of page 118), describes a DTS installation monitoring the condition of pipework associated with the filtering in a pressurised fluidised bed combustion (PFBC) power generating plant in Japan.

By coincidence, four steam lines are a common arrangement at a nuclear power station, so the DTS installation at this PFBC power station is a useful reference design.

3. APPLICATION NUCLEAR POWER STATION STEAM LINES

3.1 Steam Line Leak Detection

If conventional point temperature measurements are used, subjective decisions have to be made about where steam leaks are most likely to occur, because it would be practical to only install a few individual temperature points because of the large quantity of separate wiring per point that would be required.

The advantage of the DTS system is that very comprehensive temperature measurement coverage can be provided over the whole length of the steam lines in a practical and relatively economic way so that no subjective decisions have to be made as to where a leak might be likely to occur due to internal erosion of the pipe. Also leakage of steam lines caused by other low probable external events would also be covered.

In considering the possible application of DTS for leak detection on the steam lines of a nuclear power station, the following points are relevant;

3.2 Temperature Resolution v Time

There is a trade off between measurement time, temperature resolution and length (range) of the fibre-optic cable. The above PFBC application of 4km sensor cable, has a temperature resolution of 0.5 deg. C; hence the relatively long scanning time of 2 mins.

However a resolution of 1 deg. C can be achieved in a measurement time of 20 seconds, and 5 deg. C in 5 seconds. One of these may be a more appropriate specification for nuclear steam lines where speed of alarm response to a high temperature differential may be desirable.

3.2 Double Ended Sensor Configuration

The fibre optic sensor cable can be measured at both ends which provides the following advantages in a safety critical application;

- signals are not interrupted if there is a break in the cable.

- break in the cable would be alarmed to the operator.

- dynamic loss variations along the sensor fibre elements are compensated, thus optimising signal-to-noise performance.

3.2 Fibre Optic Cable Specification

The fibre optic cable requires is Standard Communications Grade G1 multimode optical fibre, but there is a choice of both the fibre optic sensor element and the secondary sheathing depending on the temperature rating required and the physical protection desired.

For example, a polimide primary mechanical coating has a temperature rating up to 385°C.

The secondary sheathing of plastic might be appropriate for this application, but stainless steel would be better. The cable would have an overall diameter of about 2mm.

3.3 Coverage Possible

The approach in developing the technical concept was to identify the maximum possible coverage that could be achieved by utilising the 4km length of sensor cable in four loups, as used in the PCFB example.

The initial concept was for the fibre optic sensor cable to be run as a spiral "Bobbin" winding pattern around a main steam line which has an overall external circumference of about 2.5 metres. This would provide 10 temperature "points" per metre of pipe length. This should be the maximum coverage of temperature points that could possibly be required to detect an increase in local temperature due to a postulated steam leak. This spacing may be much smaller than really required.

In the above arrangement, 4 km of fibre optic cable could monitor a total of 300 metres of steam lines, allowing 100m of cable for connections back to the DTS equipment in the main control room. The longest steam line was assumed to be 100m.

Each of the four steam lines would have a separate double ended loop connected to the DTS terminal equipment, similar to the connections and data processing of the PFBC reference design.

3.4 Average temperature

The DTS system can calculate various reference temperatures;

- An average temperature for the sensor cable along the whole length of a steam line.
- The external ambient temperature.
- Absolute temperatures of each "point"

Temperature increase of any "point" above a margin set on the reference temperature(s), would be is alarmed.

4. INSTALLATION OF THE FIBRE OPTIC CABLE.

4.1 Practical problem of cable installation.

The application of the "bobbin" pattern would require winding one km of sensor cable around a 100m long steam which would present the following practical problems;

- the steam line has many bends, supports, restraints ("snubbers"), and flow measuring tubing connections, which would have to be circumvented.

- After a few turns, the fibre optic cable would be very difficult to feed out and could get in a knot.

- Many splices in the cable would be required as obstructions are passed and the cable is tightened.

- If during subsequent service, repairs to the insulation or inspection of the actual pipe was required, the fibre optic cable would be to be broken and reconnected. Such reconnections are possible and would only result in a small loss of signal, but it would be desirable to minimise such joints.

It became obvious that "bobbin" winding pattern would be unpractical, so the following alternative cable patterns were considered.

4.2 The "Straight" run of cable.

In the "Straight" option, 10 parallel sensor cable runs would be required to give the same coverage as the "Bobbin" pattern used in the above calculations providing the "maximum possible" coverage.

It may be that this "maximum possible" coverage is not required, and that two parallel cables would suffice; one cable along the top of the steam line (at 12 o'clock) and one along the bottom (at 6 o'clock) with perhaps supplementary runs on each side (at 3 o'clock and 9 o'clock).

The disadvantages of this sensor cable pattern are;

- On a steam leak, alarms would be generated by more than one of the "straight" cables. This would not matter in the case of a major leak, when the operator action would be to shutdown the plant, but might cause confusion in the case of a small leak.

- It is a requirement that a cable pattern should appropriate for either a horizontal or vertical length of steam line, both in terms of installing the cable and in terms of the flow of steam from the leak through the insulation. It is not clear how the "straight" pattern would meet the latter requirement.

- This pattern does not take full advantage of the coverage capabilities offered by a DTS system.

- There are the other disadvantages similar to the "bobbin" method.

4.3 The " U-Turn" winding.

A simple small scale model of a steam line was made to try out alternative cable installation patterns.
The "U-Turn" or "serpentine" pattern was conceived, as shown in the attached Figures 1, 2, 3 and 4.

This pattern turns out to have some interesting advantages as described in the figures, and makes the installation more practical. The coverage of the cable would be adequate for both a horizontal or vertical steam lines.

5. LOCATION OF THE SENSOR CABLE.

5.1 Steam line Cross section

A typical steam line cross section comprises, described from inside to outside;

- The steam pipe
- Two 2"(5mm) thick layers of hard Calcium-Silicate insulation.
- An aluminium sheathing.

There are three possible optional locations for installing the fibre optic cable;

5.2 Outside of the aluminium sheathing.

It may seem easier to install the sensor cable outside the aluminium covering, but has this location has the following disadvantages;

- The sensor cable would be sensitive to external temperature, such as the sun. It is possible to compensate for these external effects by data processing. For example, one circumference of sensor is about 2.5m and could be considered as four overlapping one metre temperature "points". The temperature readings of all the points having the same orientation could be averaged along the whole length of the steam line, and increases above this average alarmed.

- The sensor cable would have to be affixed to the aluminium with a temperature conducting paste.

- Damage to the cable; a stainless steel sheathing would offer some protection.

5.3 Between the aluminium sheathing and the top layer of insulation.

It is fairly easy to install the cable between the aluminium sheathing and the insulation, because the insulation is removable in convenient sections. The aluminium would prove some shielding from external temperature effects and would provide good physical protection.

5.4 Between the two layers of insulation.

Locating the sensor cable between the two layers of insulation would be ideal from considerations of shielding from thermal effects, but on an existing plant, requires the removal of one layer of insulation.

6. TEST RIG

It may be that a sensor cable in any of the above alternative locations would give a satisfactory indication of steam leak which should cause a significant increase in the local temperature of the insulation well above the average temperature as measured along the total length of the sensor cable for the individual steam line.

It is planned to determine the optimum location of the sensor cable and to demonstrate the performance of the DTS system on a test rig in Canada. This test is already partially erected and comprises a 3 metre length of full size steam line with the same cross section as described above. This test line has been arranged to simulate a variety of different sizes of steam leaks.

The sensor cable will be installed in the three locations described above and in both the "U-turn" and four "straight" patterns.

Tests will determine the comparative response of the various locations, patterns and the spacing required between the turns of the sensor cable to obtain the desired indication of a specified steam leak. Results should be known before the end of this year.

7.CONCLUSIONS

The inventor and supplier of the DTS system has stated that there are 82 DTS units in service in different countries in a wide variety of applications, with an average mean time between failures of 6 years.

One DTS unit has been in satisfactory service in Canada for a few years on an electrical power application.

Tests have already been successfully carried out on test length of steam line at a coal fired power station in the UK, but using a "straight" pattern of sensor cabling.

The author has witness demonstration tests of the response of the DTS system to heat applied to a one metre length of one km coil of sensor cable. The distributed temperature sensing technology appears to be reliable commercial product.

The application of DTS to the detection of leaks in steam lines seems to be a matter of specific application design, selecting a practical pattern and acceptable depth of location of the sensor cable installation, and the desired processing of the temperature data and presentation to the operator.

Temperature is a well understood phenomenon and should be easy to interpret by the operator.

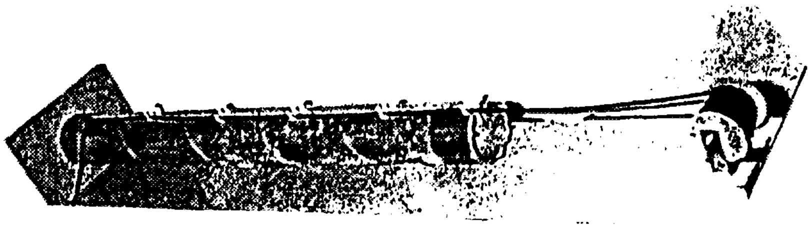
The tests planned to be carried out in Canada in the near future should indicate the optimum application design.

ATTACHMENTS

Figures 1,2,3 and 4 of the "U-turn" sensor cable pattern

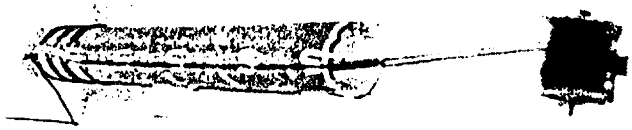
REFERENCES

[1] Arthur Hartog of York Sensors Ltd., June 1995, "Distributed fibre-optic temperature sensors" Power Engineering Journal, U.K.



The start.

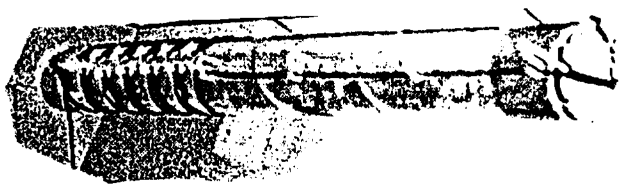
An initial length of cable has been drawn off the cable drum at one end of a section of steam line, and pulled along through by 5 pulleys (white), to the other end of the steam line.



A few turns on.

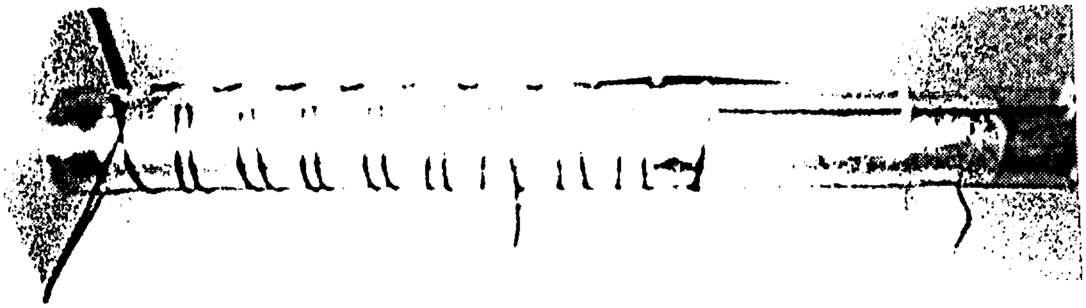
Cable has been drawn off the cable drum as required.

The "U-Turn" fixings (yellow) at the top of the steam line are shown.



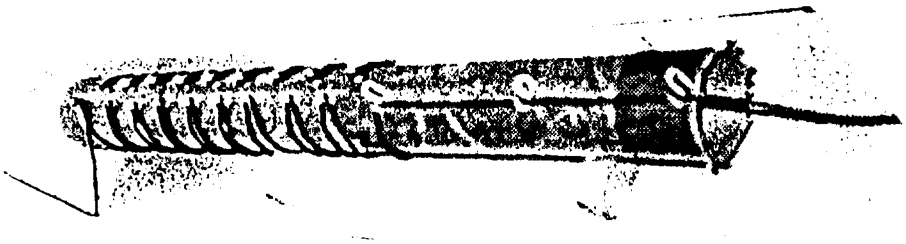
FIBRE-OPTIC CABLE "U-TURN" PATTERN
INSTALLATION PROCEDURE

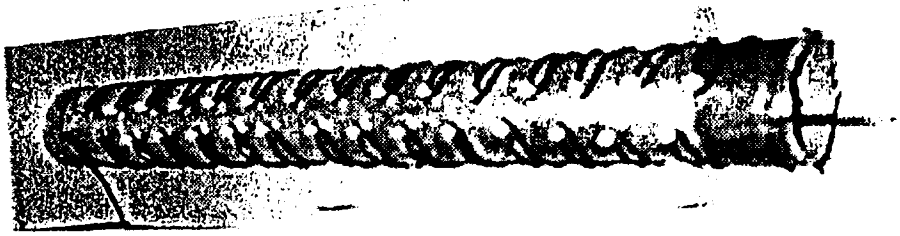
Fig. 1



Half way;

This shows how the cable passes an a typical obstruction such as a pipe support.





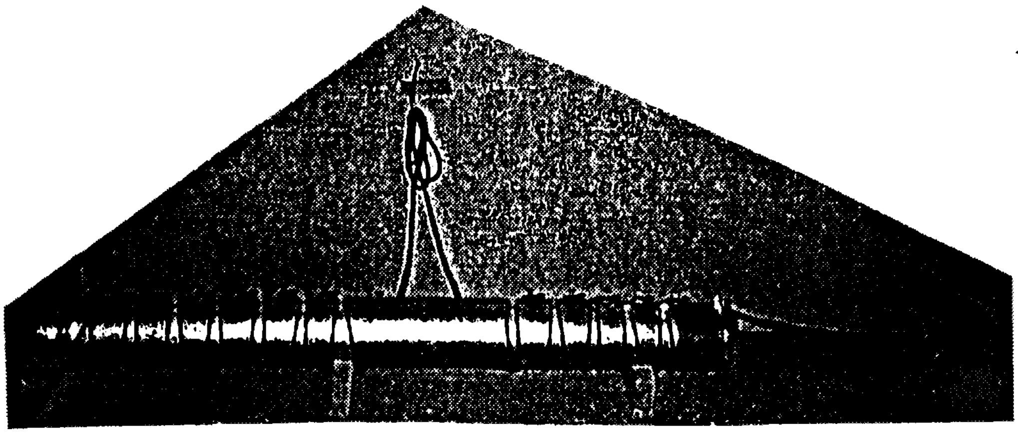
Cable installation complete.

The "U-Turn" support fixings are shown farther apart for clarity.

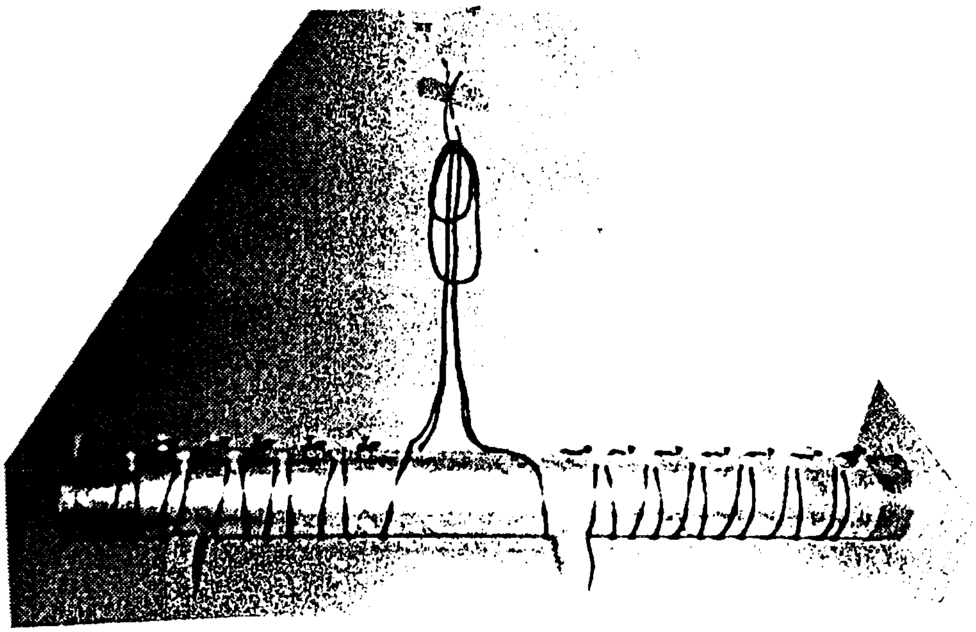
This shows how the cable passes typical obstructions; two pipe supports.

FIBRE-OPTIC CABLE "U-TURN" PATTERN
INSTALLATION PROCEDURE

Fig. 2



Access for repairs/inspection of the insulation or the pipe;
cable removed over.



Access for repairs/inspection of the insulation or the pipe;
cable removed under.

The cable is pealed away from the steam line without cutting the cable or requiring splice joints on reassembly.

(The apparent double cable is a shadow)

FIBRE-OPTIC CABLE "U-TURN" PATTERN
INSTALLATION PROCEDURE

Fig. 3

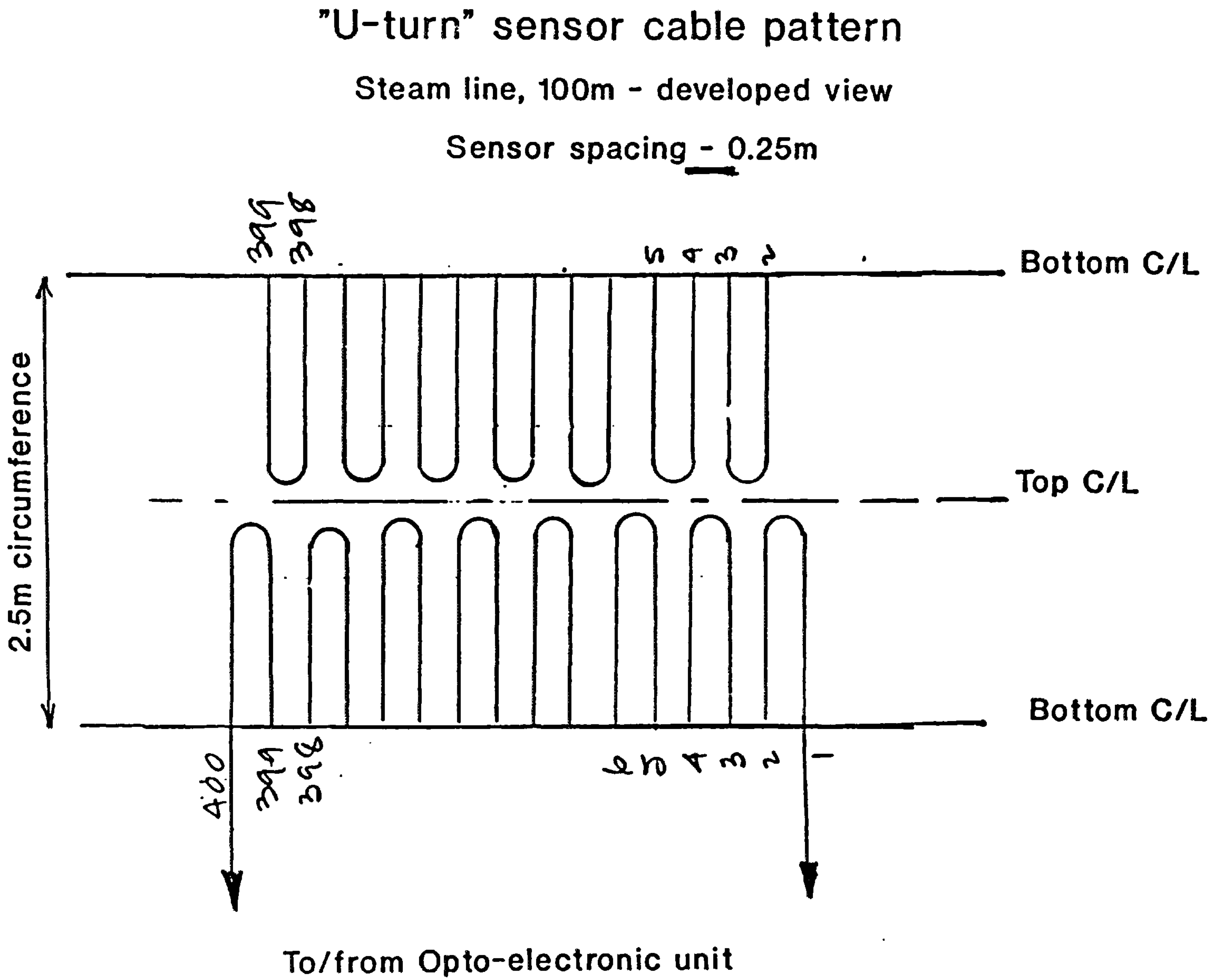


Fig. 4 - "U-turn" senor cable pattern