Electromagnetic pipeline survey systems

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IN THE LATE 1970s, surveying buried pipelines from the surface without excavation was a 'black art'. Depending on the circumstances, an experienced engineer might be able to locate a proportion of the faults in the coating but, inevitably, an unknown number would be missed which could, in time, lead to corrosion and possible pipeline failure. At that time we had discussions with a major UK operator of cross-country gas transmission pipelines who asked us to look for a fundamentally-new approach to the problem. We needed technology that would be accurate, consistent, comprehensive, repeatable, and economical in both time and labour.

The basic idea underlying most survey systems is to apply a signal of some kind to the pipeline. This can escape through faults in the insulating coating or wrapping and some part of that escaping signal may reach the surface above the pipeline and may be detected by electrical contact with the ground using spiked boots, probes, or half-cells. Detection of the signal would indicate a probable 'fault' in the pipe coating below. The first of these 'ground-contact' systems was the Pearson system, and other ground-contact systems appeared subsequently. These systems have limitations that are well known and had been accepted, but the continuing demand for higher safety standards, and the cost and consequences of failure, meant that something better had to be found.

Fig.1. Survey using a C-Scan 2010 detector unit for a pipeline at a stream crossing.

The ground-contact survey is essentially subjective, often depending on the knowledge, skill, and experience of the individual operator. The instrument is ineffective if there is a non-conductive surface over the line (tarmac, concrete, etc.), and it can easily miss some faults where the pipeline is too deep, the escaping signal is too small to reach the surface, or where the pipeline has recently been excavated (for repair or modification) and the backfill has not had time to consolidate and provide a good conductive path from the pipeline to the surface. A nil reading at the surface can therefore mean that the pipe beneath has no faults, or that there is no readable signal, or even that the operator is not over the pipeline at all. A review and check of many pipeline survey reports, and subsequent discussions with the surveyors, has shown that some had been rated 'excellent' because the pipeline was actually on the opposite side of the road to the route of the regular survey! Other lines had 'good' to 'excellent' ratings because sections under roads or streams were simply ignored as 'no signal was obtainable' through the tarmac or the water. The biggest underlying problem with all these methods is that 'no signal' is taken to mean 'good condition'.

The survey data obtained at each location relates only to the pipeline immediately beneath the operator's feet. It cannot tell him anything about what might be happening a few metres further along the pipeline, and so every metre of the line has to be accurately marked, walked, and probed – a slow, tedious, and unreliable process that almost certainly misses a significant proportion of any faults that might actually exist.

Reversing the approach

The approach finally adopted was a simple reversal of the traditional approach. Instead of trying to find only the places where the signal was escaping through the wrapping and reaching the ground surface, we would try to measure the strength of the signal remaining on the pipeline at any point and hence the amount of signal lost between any two measurement locations. This removed the uncertainties of relying on direct electrical contact and using the changes in the electromagnetic field being radiated by the pipeline. So, if such a system could be made to work, it could provide a comprehensive report on the condition of the coating or wrap, including all the faults, between any two survey points without having to walk the line, and without being affected by the nature of the ground surface. This offered a substantial saving in time and effort, combined with a massive increase in data accuracy and consistency – a prize certainly worth having.

A key member of our development team was the late Mark Howell, holder of many patents in this field, who had earlier invented and patented the electromagnetic pipe locator and *Cable Avoiding Tool* (CAT), and his brilliance was the real foundation for this company's efforts. The starting point in the development programme was the electromagnetic pipe locator. The geometry of the typical pipe locator is basically two identical horizontal-axis inductive coils, one above the other, about 300-400mm apart. When their axes are at right angles to the pipeline below (which is carrying an AC signal), they can pick up the radiated field inductively. The ratio of the field strengths picked up can give an approximate indication of the pipeline depth. A third, vertical-axis 'null' coil can be added to ensure that the instrument is approximately over the pipeline. A large coil placed on the ground surface further along the line (the signal generator) applies the initial signal to the pipeline inductively.

A series of field trials with different pipe locator configurations showed that such a tool could usually indicate the presence or absence of a pipeline; but the data obtainable could not provide the accuracy necessary to determine the true rate of loss of signal current along the line, and hence the location of faults and general coating quality. To obtain a precise measurement of signal strength on the pipeline at any point requires the accurate measurement of the true field strength at two or more points vertically above the pipeline at the largest feasible vertical separation. It was readily apparent that with two simple coils and a separation of only 300-400mm, this accuracy could not be achieved on a typical pipeline.

If the system uses single coils at the top and bottom, the instrument must assume that the horizontal axis of each coil is precisely at right angles to the axis of the pipeline. Research has showed that an error of less than 20° in the orientation of the antenna could easily produce an error of over 6% in the reading of field strength obtained (over a pipeline at 1.5m depth). Since the basis of the current-attenuation survey system must be the accurate measurement of relatively-small differences between the signal current readings at one location and the next, this single source of error could easily be enough to invalidate a complete survey.

Fig.2. The C-Scan detector unit at work on the bed of a 10-m deep frozen river in Canada.

The solution was to develop a new antenna using two or three coil sets, each with three mutually-orthogonal coils. The overall length of the antenna was also substantially increased. At each coil set, the outputs from the three coils present were used to calculate the vector sum – and hence the true strength and direction – of the field at that point, while the increase in length improved the accuracy, an essential part of the calculation of remaining signal strength. Combined with a number of other developments, such a system proved to be far more accurate, possible to operate over deeper pipelines, and was virtually immune to the effects of interference and orientation error.

Maintaining the signal

Another important factor in carrying out an accurate survey is to ensure that the initial applied signal remains absolutely constant once set. From this it was clear that the signal itself could only be applied by direct connection to the pipeline. A system was developed that ensured that the applied signal, once set, did not change (until its power source was exhausted), whatever the changes in the external environment. The selection of the main operating frequency and waveform was a matter for compromise. A low-frequency (LF or ELF) signal would travel further along the pipeline but, because of inherently-poor inductive coupling with the antenna, the data collected would be much less accurate. Such a signal would also be liable to interference from other signals present in the environment. A high-frequency signal could give better-quality data, but would travel over a much shorter distance. Finally, a main frequency of 937.5Hz was

Fig.3. Making connection to CP test post in Saudi Arabia.

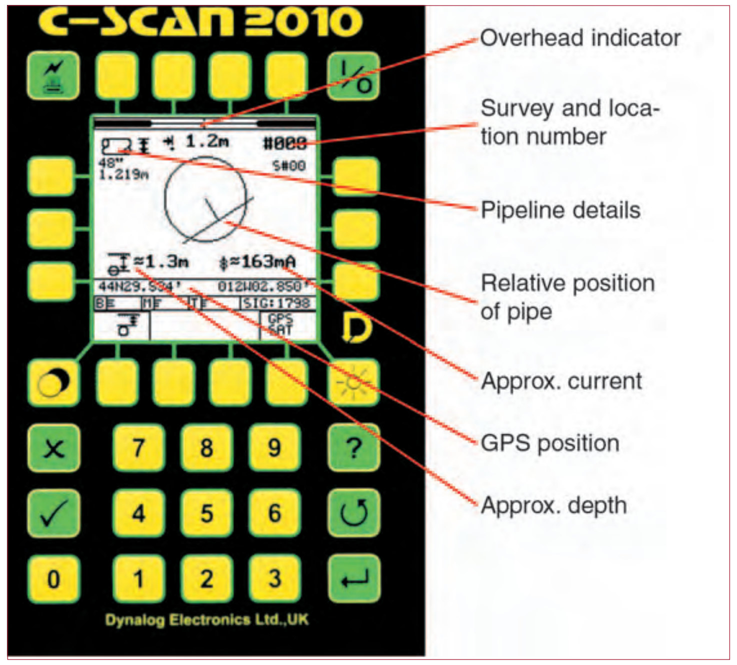

Fig.4. The C-Scan 2010 detector unit operator interface screen and keyboard.

selected, using a 'clean' sine wave; this was found to give reasonable range, excellent inductive coupling between the pipeline and the antenna, and the absolute minimum of possible interference from commonly-occurring ambient harmonics. Combined with precise tuning of the detector antenna and the use of extremely-fine filters, this has proved extremely satisfactory, permitting detailed surveys of pipelines on river beds and in estuaries at depths down to over 15m.

To avoid transient interference or distortion in operation, the detector automatically collects many samples of survey data in the space of two or three seconds and analyses these immediately, checking for variability. Accepted data is stored against the survey number, location number, and date and time and, if required, the position indicated by the built-in GPS system. At the next survey point, which may be anywhere from 100 to 1000m away, the process is repeated. The instrument displays the distance between the readings and the logarithmic attenuation of the signal (in milli-Bels/m) between the points. It will also show the average conductance (micro-Siemens/m^2) or resistance (kOhms/m^2) of the wrap over the section, if this is required. Logarithmic signal attenuation as a criterion, is used rather than loss of signal current per metre, as attenuation is not affected by the absolute value of the applied signal, and makes comparisons easier – either section-by-section, or with earlier or subsequent surveys of the same line.

With this equipment, it is possible to produce a comprehensive survey and printed report on a buried transmission pipeline at rates of 20-50km/day. The system software can automatically generate maps, plots, and tables covering virtually every significant aspect of the pipeline. These can include comprehensive coating condition surveys, pipeline mapping, QA/QC surveys checking on new pipeline construction or repair and rehabilitation projects, surveys of inaccessible pipelines under rivers, mud, ice or growing crops, check surveys for possible damage caused by engineering work, checks on the effects of scouring on river beds, checks on changes in pipeline cover at landfall on offshore lines, checks on possible contacts with other pipelines or underground services or buried debris, and many other applications. All of these reports can be stored and automatically compared with subsequent surveys of the same line to highlight changes.

The electromagnetic buried pipeline survey system was launched in 1983 after over four years of development work. Over the last two decades, there have been three major re-designs and there is a process of continuing development and improvement of hardware and software using in-house resources and feed-back from customers, who include major pipeline owners and operators in 45 countries around the world. Software upgrades are regularly available to existing customers via the internet, which is also used for diagnosing faults and assisting with survey problems.

The technology described here meets or exceeds the requirements of the NACE Standard RP0502-2002 (*Pipeline external corrosion direct assessment methodology*), NACE Standard TM0102-2002 (*Measurement of protective coating electrical conductance on underground pipelines*), as well as other national and international standards.

Fig.5. Diagrammatic representation of the signal generator and how it is applied.