Magnetism, A New Force in Cable Protection

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Abstract

The submarine cable industry has been moving toward deeper depth of burial (below the seabed) and deeper overall cable burial (water depth). Also, the submarine cable industry has moved from copper to optical fibers for signal transmission, the cables have become increasingly smaller and the amount of ferromagnetic material in them has been drastically reduced. Many festooned cables are also being constructed so that they contain no copper or other means for electrical signal transmission in them at all. These cables have become very difficult to locate and follow underwater. Additionally, cable landing sites are having a greater number of cables installed. The ability to accurately determine cable location during PLIB has become more difficult. These circumstances provided a challenge to the industry and our engineers have invented a technology application, which has the potential to meet those challenges and mitigate the increase in repair times (and costs) and RFS times (and costs) that have resulted from those industry trends.

A new technology application has been developed to organize and enhance the magnetic signature of submarine cables. The process uses groupings of permanent rare earth magnets to impart a predetermined magnetic signature to the ferromagnetic material (either armor or king wire) in the submarine cable. The operation is undertaken either during cable loading or on board the cable ship during cable laying operations. The result is a dramatic improvement in the ability to sense, locate, and follow the cable. In addition, a variety of information can be encoded into the magnetic signature - similar to a 'bar code'. Examples are; identity of the cable, distance marking, changes in fiber type. By improving the efficiency of the installation and repair operations; the overall system economics can be improved. Installation and repair timelines (and costs) can be reduced, repair solutions can be simplified, and a more efficient, more reliable submarine system can be produced. This paper will briefly describe the magnetization process and investigate and discuss the positive economic impact that magnetizing the cable can have on installation and repair costs, as well as the impact on overall system economics using data from our testing and actual installations, where possible. In addition, the impact and potential for future improvements in installation and repair technology will be discussed

Background:

Aggregate telecommunication system availability depends on three factors: system reliability, cable protection from external sources of aggression and time to repair the system. Reliability is the probability that the system will perform its specified function in a given environment for a specified period. In other words it is quality over time within its in-situ environment.[i]. The levels of availability dictated in this industry are necessitated by customer demand for highly reliable communication links and the economic harsh penalties in the marketplace for lack of reliability. The explosive demand for bandwidth coupled with the increased dependence on communication have challenged the system suppliers to put previously redundant systems into mainstream service and architecturally create self-healing networks which assure communications paths for subscribers. The stakes are extremely high in this serious business.

Reliability is one of the most significant benchmark characteristics of the submarine telecommunications industry. Tremendous effort is put forth by the submarine system manufacturers to guarantee reliability of the electronic, electrical and mechanical components within a submarine telecommunication system. The choice of a manufacturer, installer and maintainer is sometimes made on reliability of the system and performance guarantees.

The concept of component accelerated life cycle testing, extremely low component FIT rates and modern day requirements for failure resulting in ship intervention of less than a single ship repair in 25 years is unique in this industry. Other industries have reliability requirements as stringent (spacecraft) but the lifespan of those systems are considerably less. The 25-year system life is unique to our industry and is built on the hard earned experience of those that preceded us.

It is against this background and industry expectations that the challenge of cable protection resides

Significant efforts have been made in creating synergistic strategies for cable protection. Many papers and presentations have been given at ICPC and the various other conferences on the subject.. I would broadly characterize the protection strategies as follows; **knowledge based** (pre-installation surveys, local knowledge of fishing and anchoring), **avoidance** (move cables from areas of fishing and anchoring, and ultimately, **cable burial**.

Given the maturation of the industry regarding the surveys necessary for system engineering, operational planning and regulatory requirements, I would assert that there exists the necessary means to understand the marine geology associated with planning a cable installation, if one is willing to pay for it. Combining this geophysical data with local knowledge depends heavily on obtaining dependable local knowledge This can be a challenging activity due primarily to the lack of scientific verification which can be obtained. When coupled with a plan that avoids areas of likely external aggression, it will establish the best route from which to work the cable burial strategy.

Early cable burial was primarily limited to the depth that could be achieved by the plow. Obviously soil dynamics played into this as well as the ability of the tow system to exert towing force in a controlled manner. However, engineering and ingenuity provided momentum in providing the capacity to bury cables deeper into the soil at greater ocean depths. Deeper burial seemed to be a good strategy, and continues to be the trend.

Clearly, trends toward deepwater burial below 2000 meters have abated. However, the trend toward deeper burial into the seabed has not. Burial increased from 0.6m in the early 1980's to 1.5m – 3m more recently. Even deeper burial is sometimes required in very soft soils, and consequently, pressure has increased on equipment suppliers to improve their capability to locate and track submarine cables that have been buried deeper into the soil. Some believe that this requirement has been keyed to the emerging capabilities of the burial plows. It is not clear if the key driver is plow push or protection pull, but in any case burying cables deeply for system reliability is the accepted trend in the industry.

How and why the cable was placed deeply into the soil is of little consequence relative to the purpose of this paper. Just the fact that it is in the soil and it needs to be located, and the depth of burial needs to be determined is sufficient for equipment suppliers to find ways to meet this requirement. Verification implies positive data and therefore the notion that a cable is out of sight and below the range of a sensor has become insufficient for cable protection or permit verification purposes.

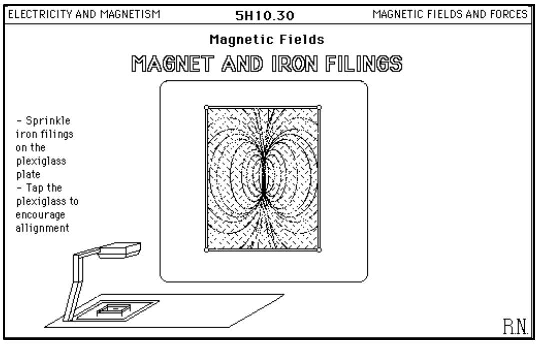
Positive data has become essential for cable protection and other required verification. My talk today focuses on how to achieve that positive data.

Magnetics Basics: [ii]

The fact that iron can be magnetized (the ability to attract other iron) has been known for thousands of years, but the explanation of this phenomenon has awaited the recently acquired knowledge of atomic structure. It is this force of nature that is being applied to the cable protection problem. An excellent web page for further investigation of the history of magnetism is located at:
http://history.hyperjeff.net/electromagnetism.html

All non-acoustic devices which are utilized to track cables underwater use some form of electro-magnetics.. Understanding a few fundamentals of physics will facilitate understanding the concepts I will discuss.

First, I want to go back to science class to review magnetization. You might recall this experiment that demonstrates the shape of magnetic fields.



The earth itself has a magnetic field, with its magnetic poles being some distance from the geographical poles.[iii]

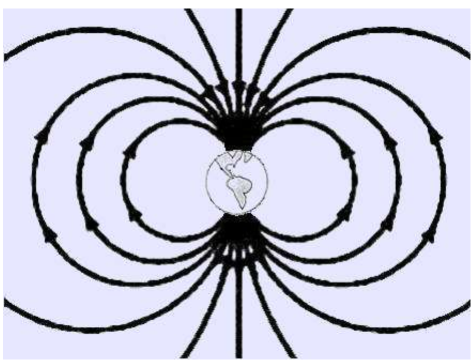


Figure -The magnetic field of the earth.

However, in tracking cables the total earths field is not a major consideration.

The magnitude of the earth's field dwarfs the local field created by a cable. Instead field gradients or local fields are the phenomena that are measured.

As such, local influences (ROV) must be considered in sensor design. Utilizing a tracking system that has a gradiometer array allows measurements of these fields very accurately and thereby permits extremely accurate buried cable location.

According to theory, the magnetic field around a current carrying wire and the magnetism of a permanent magnet are the same phenomenon fields created by moving electrical charges. This occurs whether the charge is moving along a wire, flowing with the magma of the earth's core, encircling the earth at high altitude as a stream of charged particles, or rotating around the nucleus of an atom. This premise allows direct evaluation of Tone, Impressed Magnetization and Pulse Induction techniques.

It has been shown that microscopically small regions, called domains, exist in iron and other ferromagnetic substances. In each domain the fields created by electrons spinning around their atomic nuclei are parallel to each other, causing the domain to be magnetized to saturation

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In a piece of unmagnetized iron, the directions of the various domains are arranged in a random manner with respect to each other. This is the case of telecommunications cables delivered from the factory for installation.

If the cable is placed in a weak magnetic field, the domains rotate somewhat toward the direction of that field. If the field is made sufficiently strong, entire domains rotate suddenly by angles of as much as 90° or 180° so as to become parallel to that "crystal axis" which is most nearly parallel to the direction of the field. If the strength of the field is increased to a certain value depending upon individual conditions, all of the domains rotate into parallelism with the field, and the iron itself is magnetically saturated.

Magnetism that is present only when the material is under the influence of an external field is called induced magnetism. That which remains after the magnetizing force is removed is called residual magnetism (impressed magnetization). That which is retained for long periods without appreciable reduction, unless the material is subjected to a demagnetizing force, is called permanent magnetism. This is the case for the Innovatum Magnetizer System

An informative web page on magnets is located at http://www.hegao.com/engineer.htm#mag

Certain substances respond readily to a magnetic field. These magnetic materials are principally those composed largely of iron, although nickel and cobalt also exhibit magnetic properties.

The present-day materials of submarine cable construction are adequate for impressed magnetization. However, 3U Technologies is undertaking a program to characterize a significant number of underwater cables with the intent of establishing magnetization effectiveness on a significant sample of cables. This data could lead to armored cables, which can be magnetized with greater signatures, thereby allowing greater location, tracking and mensuration ranges.

Field test results have shown that a 17mm single armored cable has a magnetic signature as shown in the figure below.

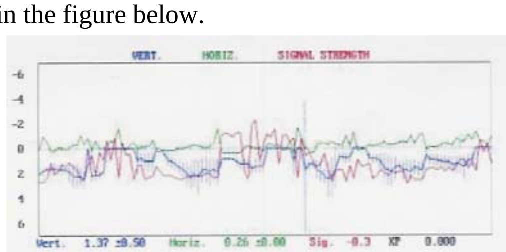


Figure 1. Before Artificial Magnetization, Surveyed From 2 Meters.

By properly organizing the field utilizing the Innovatum Magnetization Process, the field has been increased from 30-50 nT to 8,000-12000nT. This 2+ order of magnitude increase in effective magnetic signature facilitates tracking and verifying cabled which have been buried at the extremes of present and, anticipated, plow capability.

Actively enhancing the signature of a cable to facilitate verification and protection of undersea cables is a notion whose time has come.

Cable Locating and Tracking Techniques

Cable Tracking, regardless of which equipment and technique are used, must obey the laws of physics. As such, when you take a look at the differences in performance for cable tracking, several factors influence how well you can do it. Specifically, The cable signature (which can be intrinsic or active), the sensor characteristics (which include sensor characteristics, sensitivity, distance to cable, and SNR created by the ROV signature) and finally, the signal fall off rate. All these factors are important, however It is our contention that the rate of signal falloff (or lack of) is the single most relevant characteristic to effective cable locating and tracking

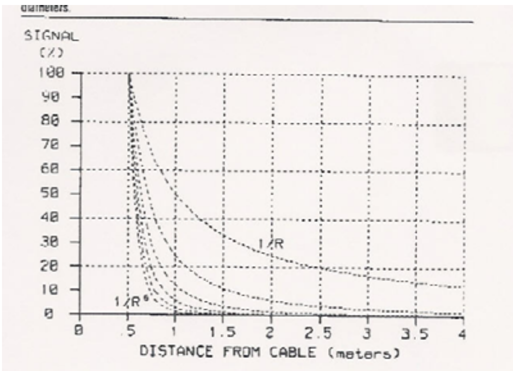
.

The Cable Signature

As Submarine Cable has moved from copper to optical fibers for signal transmission, the cables have become increasingly smaller and the amount of conductive or ferromagnetic material in them has been significantly reduced. The magnetic signature of an unmagnetized telecommunications cable is approximately 30 to 50 nano Tesslas. Festooned cables are also being constructed so that they contain little or no copper or other means for electrical signal transmission in them at all. The result is cables have become increasingly difficult to locate and follow underwater. Traditional acoustic means of tracking oil pipelines produces unreliable results due to the small size of the cables compared to the wavelengths necessary for soil penetration.

Sensor Characteristics

Cable tracking sensors fall into 4 classes: D.C. Electric Current, A.C. Electric Current (or toning/electroding), Transient Electrical Current (or pulse induction) and Magnetization. Dr. Paul Cloutier provides an excellent discussion of these techniques in a recent Marine Technology Society Journal article.[iv] The graphic below depicts the various decrements of signal as distance from the cable increases.



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Dr. Cloutier's paper asserts that, excluding D.C. Electric Current, all techniques work equally well when the cable is 0.5 meters from the sensor.. As the cable moves further from the sensor, the signal fall off increases and can be evaluated for the signal available for location and ultimately tracking and mensuration. Obviously, the local effects which impact the signal-to-noise ratio must also be taken into account.

DC Electric Current has a favorable signal falloff rate. However, the signal strength is very small to start with and therefore is less desirable for cable tracking than the following methods.

Toning the cable provides smallest rate of signal falloff but the practical range a cable can be toned is around 200 Kms from the shore station and toning is impossible on a severed cable. Finally, the operational coordination necessary to have the tone applied so that the offshore operators can utilize it is not insignificant.

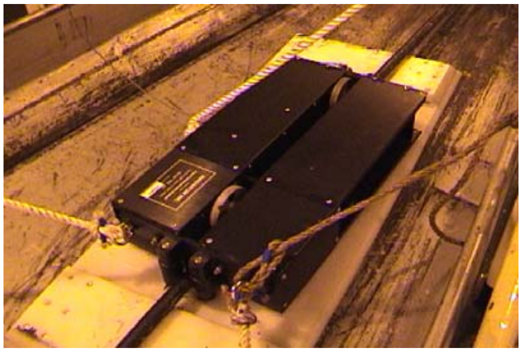
Impressed magnetization has gained acceptance in the industry and as with many new technologies, additional applications and uses are being created once the installers and maintainers are exposed to this equipment and technology and realize it's potential. Outside the range of cable toning, this technique has the next smaller rate of signal falloff. When utilized with armored cables, this technique can create a magnetic cable signature equivalent to an 18 inch steel pipeline 1 meter from the pipe axis. This technique has been tested in our test facility in Bryan, TX and also has been extensively utilized in the field. Recent comparison in the field with a pulse induction system demonstrated the impressed magnetization capabilities to be more than just assertion.

Finally, pulse induction, which relies on the metallic content of the cable for performance, has a higher fall off rate that the previous two techniques. Also, the field performance of these systems installed on ROV's indicates the operational limit of tracking cables that are less than 1 meter from the sensors.

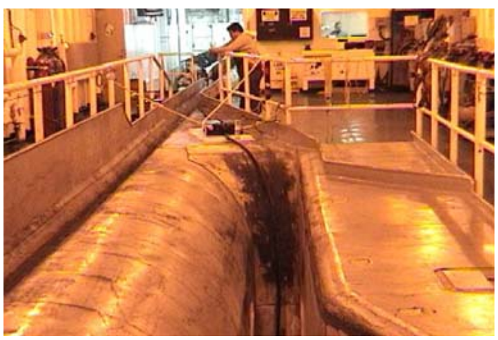
To postulate an idealized model for cable tracking, the system would have a cable which has a large signature being tracked utilizing a technique or techniques which minimize signal fall off. This scenario presents the best case for accurate tracking and mensuration. Utilizing a gradiometer tracking sensor capable of operating in multiple modes simultaneously and correlating them facilitates the evaluation task of the ROV operator and provides the best mensuration data. Incorporation and feedback of error bands further refines the mensuration data that will subsequently provide the best indication of how well protected your system actually is by meeting your specifications.
As you might expect a system which meets the idealized model exists and has demonstrated significant in field performance. Coupling the Innovatum Cable Magnetizer with the gradiometer array Ultra Tracking System provides significant capability in buried cable tracking.

INNOVATUM Cable Magnetization

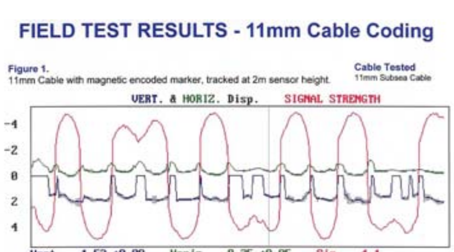
A technology has been developed to organize and enhance the magnetic signature of submarine cables. The process uses a group of permanent rare earth magnets or electromagnets to impart a predetermined magnetic signature to the ferromagnetic material (on either armor or king wire) in the submarine cable. The cable is magnetized in a particular geometry, which creates a continuously varying axial magnetization. This process creates a radial "leakage field" which falls-off at the 1/R rate. Using gradient measurement the apparent fall-off is $1/R^{2}$. This magnetization process will last significantly longer than the stated cable system lifetime. In fact, Dr. Cloutier asserts that the magnetism will likely last centuries. As our testing proceeds we plan to report at the ICPC Plenary Meeting in 2101.



The magnetization operation can be undertaken either during cable loading or on board the Cable ship during cable laying operations. The choice depends on the cable system configuration. Presently we magnetize unrepeatered systems in the factory or during loading. Repeatered systems are magnetized during laying operations. We continue testing to determine ways to magnetize repeatered systems during cable loading. The result is a dramatic improvement in the ability to sense, locate, and follow the cable over other methods.



In addition to simply locating and mensurating a cable, a variety of information can be encoded into the magnetic signature - similar to a 'bar code'.



Application examples of the benefits of coding are; ability to discriminate one cable from another, apply distance markings, and mark changes in fiber type – all improvements to the efficiency of the installation and repair operations that provide for the improvement of the overall system economics.

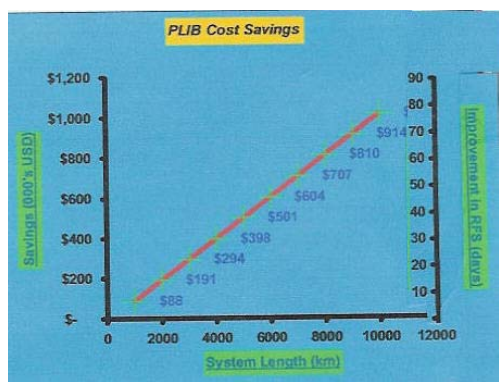
Installation and repair timelines (and costs) can be reduced, repair solutions can be simplified, and a more efficient, more reliable submarine system can be produced.

Economics[v]

The economic benefits that can be derived from the ability to more effectively locate, track, and pinpoint specific areas on cables will vary from cable system to cable system, but they can be broken down into 4 categories as shown below:

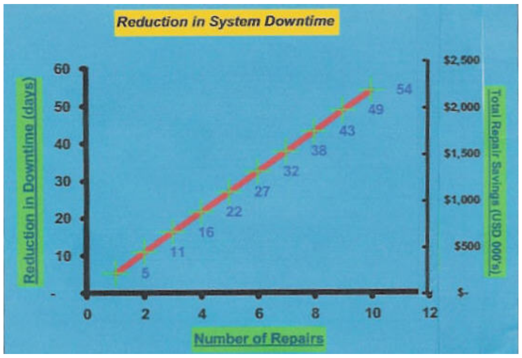
- Installation Cost Savings
- Repair Cost Savings
- Improved System Profitability
- Satisfaction of Permitting Terms that reduce liability claims

The following graphs depict potential savings that could be realized by utilization of an effective cable tracking system. The potential installation and repair cost savings is achieved largely from reduced ship time on station. This cost savings could take the form of actual cost savings or opportunity costs related to other project work.



Installation cost savings refers to reduced installation costs achieved through more efficient burial and as-built survey operations and are net of the cost to perform the magnetization process. More importantly, if PLIB operations delay the RFS date of the system the economic impact as a result of lost revenues to the cable system owners can be tremendous. Magnetizing the cable can result in much faster PLIB rates than can be achieved on a passive cable.

Improved system profitability can be achieved by allowing for earlier RFS time (at installation). As previously noted, the actual numbers vary from system to system but are indicative of time savings that are possible. The point is that the sooner a system comes on line, the sooner traffic starts flowing, and the sooner revenues begin.



Similarly, cost savings can be achieved during repair operations that result in net cost savings and reductions in downtime. And finally, the reduction in potential liability by owners to regulators by production records which verify achievement of permitting terms is a cost savings, which we have not attempted to quantify.

Future Developments

One of the enhancements for this technology currently in process is a universal ROV deployed skid for magnetizing existing in-situ surface-laid cable systems.

Another is a grapnel sensor package to indicate the approaching cable and a "smart" cut-and-hold grapnel that will use the magnetic signature to key its actuation.

Additionally, cable landing sites have increasing cable landing densities (number of cables laid in 'cable landing corridors'). Utilizing cable tracking coupled with magnetized cables which have been identity coded allows cables to be installed closer together limited only by the control of the installation vessel and plow.

Conclusions

The combination of a gradiometer arrayed cable tracker coupled with cable magnetization provides a tracking capability to meet the present and future needs of the industry. The Innovatum Ultra and the Innovatum Cable Magnetizer provide complementary and synergistic performance to help provide you the data you require and that cable protection demands.

The challenge of tracking buried linear objects is similar to the challenges faced by the underwater pipeline industry in the late 1970's. That industry evolved to a standard reinspection program for their assets. The service companies were pressed to create a cost effective capability to reinspect and confirm burial depths. The impediment within the submarine telecommunications industry will be the ability to reliably and efficiently locate and track the cable

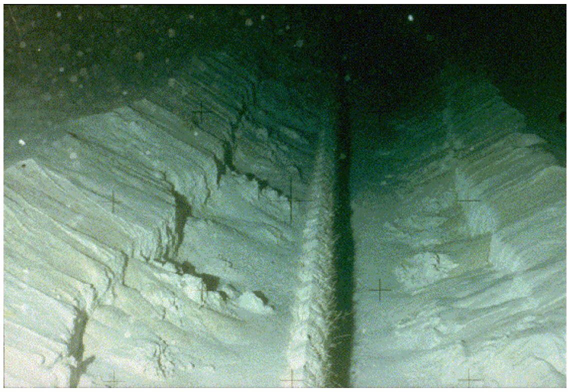
.

Magnetizing subsea fiber optic telecommunications cables provides substantial benefits to the system owner, the installation and/or repair contractor. Magnetizing cables provide the following tangible benefits:

- Reduces time to locate buried cable,
- Post Lay Inspection (X-Y position and accurate depth, Z, verification),
- Post Lay Burial (PLB),
- All PLIB - both incident to installation and future, during life cycle,
- Provides ONLY means to locate and verify deeply buried cables (1 – 5+ meters),
- Eliminates AC toning requirements,
- Enhances cable location for future cable crossing surveys and installations,
- Provides ability to locate out-of-service cables for end-of-life removals.
- Possibility to shorten RFS schedule.
- Provides proof-positive cable position data to satisfy regulators

It makes limited sense to expend significant resources to create an incredibly reliable electro-mechanical telecommunications system and then not know how well the system installation has complied with your burial specifications in cases when burial exceeds 0.7 meters.

Further, should a catastrophic event take place on a deeply buried cable, Impressed Magnetization may be the only means of efficiently locating the cable for a timely repair.



Magnetization is truly a new force in submarine cable protection.

Thank you for your time and attention. Subject to your questions, this concludes my presentation.

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[i] www.quicklogic.com

[iii] The elements of the earth's field are as follows:
Total intensity (F) is the strength of the field at any point, measured in a direction parallel to the field. Intensity is sometimes measured in oersteds, one oersted being equal to a force of one dyne acting on a unit pole. The range of intensity of the earth's field is about 0.25 to 0.70 oersted. For convenience in geomagnetic surveying, a small unit is used, called the gamma. One oersted equals 100,000 gammas, so that the range of intensity of the earth's field is about 25,000 to70,000 gammas.

[iv] MTS Journal, Vol34, No 3, p 31-34

[v]