Flex cable adds muscle to signal integrity

When designers are busy building machine vision systems, cable is often an afterthought. It shouldn't be this way. If your signals can't get from here to there in one piece, your application is running blind. To prevent that, think about cabling early in the design process, especially the metallic shields that stand guard against noise-induced signal error.

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Ethernet, Gigabit Ethernet, FireWire, Camera Link, and USB protocol are the backbone of today's digital video and motion control systems. To work properly, these networks require cabling in which signals travel on controlled impedance, differential pair conductors. Why? Digital signals common to machine vision and motion control are sensitive to impedance changes in the cable itself. This raises the bar beyond the typical cable made with aluminized polyester shields. Often, the life of the shields determines the functional life of the entire motion system.

The main problem with conventional cable is that it's not made to carry data in a high-flex environment. When such cable is used in vision-based motion systems, communication failures between the camera and system begin to show up before any mechanical wear of the cable can be observed. One solution is to use controlled impedance cables, which not only survive the rigors of millions of flex motions (from a mechanical wear-out standpoint), but also ensure reliable data links for even the fastest signal protocols on the market.

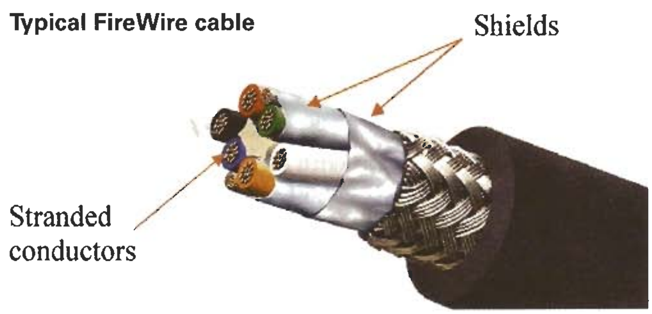
The difference between cable types is most apparent when they are tested head to head, using rigorous test methods that bring controlled-impedance cable to failure in robotic flexing applications. The results from these tests show what kinds of cables can meet the electrical requirements needed to handle the repeated flexing of automated motion-centric processes.

Understanding cable stress

Flexing a cable places stress on all components found inside the cable. Conductors and shields twist and move during flexing and shields break down. Although special insulation and conductor materials can improve resistance to flexing stress, the cable's electrical performance will change as conductors move and shields change shape or become damaged by stress.

A shield is necessary for any differential pair used in an EMI/RFI environment, such as automated work cells. EMI will induce voltage and eddy currents that attenuate the signal. For protection, most cables have an aluminized polyester foil shield. A braid or served wire (spiral) shield is often used in combination with the aluminized polyester shield for increased effectiveness.

Although aluminized polyester is a flexible shield, it won't survive repetitive motion because the aluminum cracks and sheds particles. Shield resistance increases and the openings in the shield become windows for EMI, which induce voltage



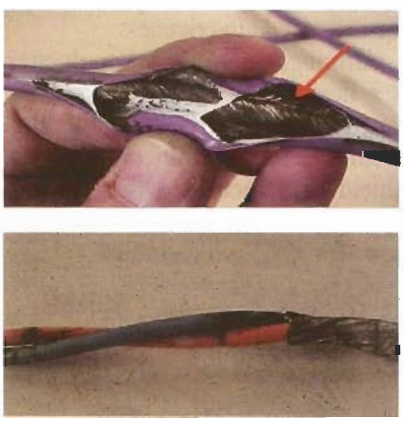
FireWire cable at work

	1394a	1394b
Attenuation		
100 MHz	2.3 dB/4.5 m	N/A
200 MHz	3.2 dB/4.5 m	N/A
400 MHz	5.8 dB/4.5 m	2.9 dB/4.5 m
800 MHz	N/A	4.6 dB/4.5 m
1,000 MHz	N/A	5.5 dB/4.5 m
Skew, within pair	400 psec/4.5 m	160 psec/4.5 m
Skew, pair to pair	N/A	N/A
Impedance	$110^{+}/_{-}6$ Ω	$110^{+}/_{-}6$ Ω
Crosstalk		
NEXT	N/A	< 5%
FEXT	N/A	< 5%

(NEXT = near end crosstalk; FEXT = far end crosstalk)

on the conductors and eddy currents on the shield wires. The result? A loss of differential signal due to increased attenuation. As the shield fails, the cable's electrical length grows shorter, and eventually the camera signal is completely lost. It's important to note that the conductors are still working at this point and the resistance of the wire has not changed significantly.

Designers should specify cable that will truly stand up to the rigors of high-flex applications. Often, it's necessary to find an alternative to the standard shield construction of aluminized polyester foil. In the foil shield family, some materials and methods of construction will provide longer-than-standard operational life, but still won't achieve the milestone of at least one million cycles typically demanded by linear motion applications.

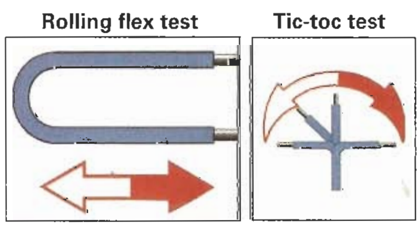


Typical FireWire cable with an aluminized polyester shield after 100,000 cycles of rolling flex on a 50 mm bend radius. Insulation and conductor damage appear where shields have cracked.

Testing, testing, 1-2-3

A flex test is an excellent method to judge cables in an "apples to apples" comparison, as it simulates a longitudinal stroke or rolling flex motion. One cycle is two complete strokes, a motion common in automation that stresses cable through the entire flex region. Flexing a long cable length under test conditions provides a functional "view" of impedance and attenuation characteristics. It's important to base cable selection on rolling flex testing, as opposed to tic-toc (or pivot) testing, to get a true picture of how the cable will perform in real-world conditions.

The flex test used in this analysis is run on a high-speed linear motion test bench with a 0.5 m stroke length. The high-speed flex tester can run 90,000 cycles/day. Each cycle is two complete strokes. Acceleration is 4 *g* and the bend radius is 50 mm.

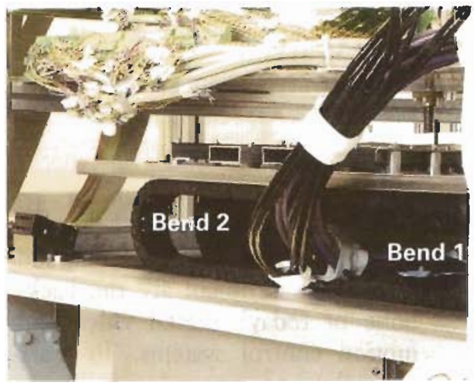


A tic-toc test does not accurately demonstrate the signal degradation problem, because the test is localized and only a small section of the cable is stressed.

Cables are placed in a cable carrier to control motion and bend radius. This test setup forms a loop with the cables that includes two bend sections. With this configuration, it's possible to stress approximately 540 mm of cable, simulating a 1 m stroke length.

In this test, FireWire cables from several manufacturers and up to four samples of each were used. After preliminary testing, only a few of the cables showed potential to last longer than 1,000 cycles of rolling flex. These cables employed a more robust shield construction, which enabled them to flex more than the other samples. One of the surviving cables used a combination of aluminized polyester foil and served wire shield on the twisted pairs, while another used a combination of copper foil and served wire shield.

Real-world results



For the rolling flex test, a signal generator and vector network analyzer are connected to the cables under test using precision, controlled impedance cables isolated from flex testing motions. Cable conductors and shield resistance are also monitored.

To provide relevant results, any cable test should evaluate electrical performance characteristics under real-world flex conditions. For vision-based motion, the following should be analyzed: impedance, attenuation, shield resistance, and jacket durability. The graphs show

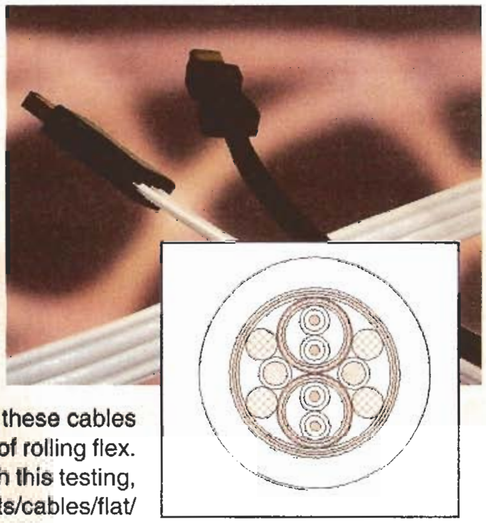
how some FireWire cables do in a battery of flex tests. Each cable has two bend sections that are in the rolling flex area; impedance increases significantly in this area as cable shields and dielectric materials break down. Cables fail when the impedance changes because the signal reflections increase and the digital signals are attenuated. The camera can't communicate with the FireWire card when the signal is attenuated.

For more information,visit www.gore.com/highflex.

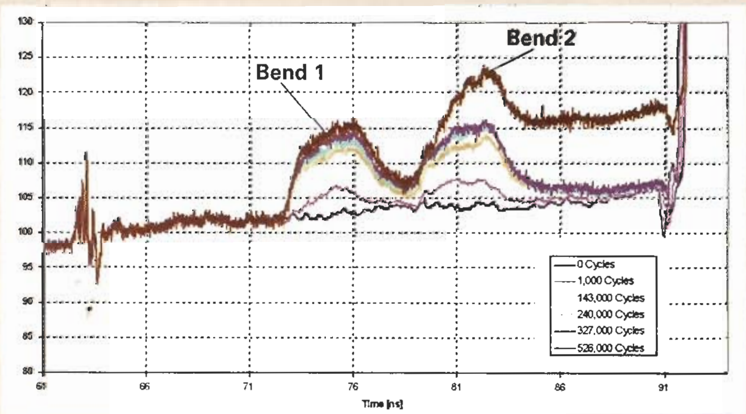
Going the distance

Enhanced FireWire cable

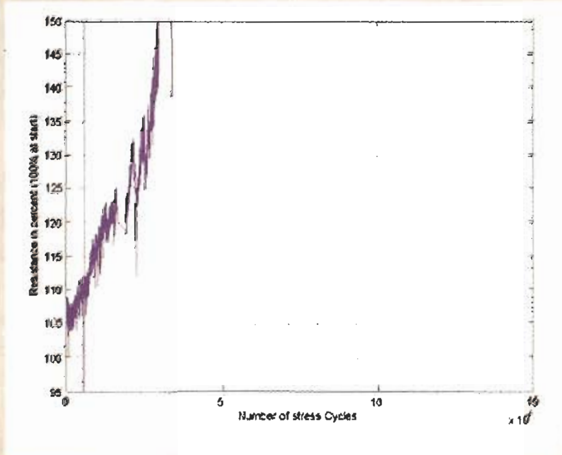
In addition to standard FireWire cables, three enhanced-construction FireWire cables with a total of six shielded twisted pairs were tested. Results showed that the impedance and attenuation of these cables is very stable for 21 million cycles of rolling flex. To view the graphs associated with this testing, visit www.gore.com/en_xx/products/cables/flat/highflex/firewire/firewire-test-data.html.



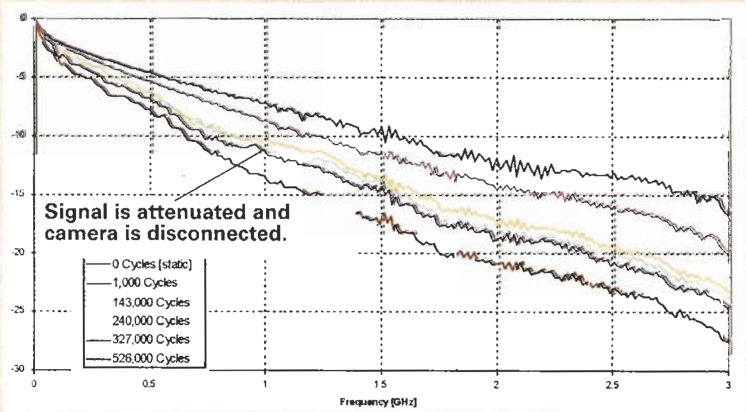
Cross section of enhanced cable.



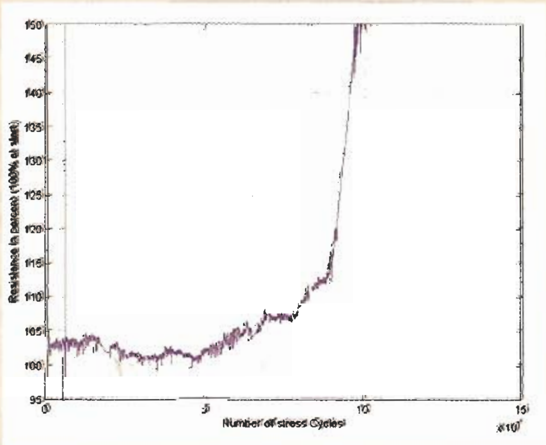
Impedance increases as flexing damages cable shields.



Conductor resistance is good up to eight million cycles. Broken shields cause the conductors to fail.



Attenuation increases when the cable is flexed.



The shield on the twisted pairs begins to fail almost immediately. Resistance increases as the shield breaks up, which correlates to the increase in attenuation at 1,000 cycles.