COAXIAL CONNECTOR PERFORMANCE

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ABSTRACT

This paper presents a series of test methods that were used to evaluate the mechanical performance of .50 inch diameter feed through coaxial connectors. The testing revealed that correctly installed connectors are as strong as the cable outer sheath, but that connectors are craft sensitive to install. Incorrect installation can lead to mechanical and hence, electrical failure.

INTRODUCTION

There have been many technical papers and articles published which address the problems of signal leakage or radiation ingress in the cable system. The cables themselves are virtually radiation proof. Connectors, amplifier housings, and taps are the principal cause of cable system radiation. When we asked the cable system operators what their problems were, the connector, one of the least expensive components, was then pointed out as a major problem. Since we could find no published industry standards on how to evaluate the mechnical integrity of the connector, we developed a series of tests to simulate the expected environmental conditions a connector could see.

As the cable system should be designed for a lifetime in excess of 20 years, test methods are used which monitor the effect of accelerated product aging. The mechnical integrity of the connection affects the connector's electrical performance and shielding effectiveness in a negative manner if it is not capable of withstanding the environmental loads. The mechnical test program was designed to evaluate a connector's strength.

CRAFT SENSITIVITY

To further the program and gain added insight to the reliability of Raychem and competitive connectors, a craft sensitivity test program was performed. The test program included Raychem technicians with good mechnical skills and CATV craft installers from local MSO's. All individuals received a demonstration of how the connectors were to be assembled in accordance with the manufacturer's instructions. The completed samples were, with the use of an Instron tensile tester, pulled in the axial direction to measure the load until failure or pullout occured.

In all cases cable jacket stripping was performed by Raychem laboratory personnel to ensure that no cable sheath nicking damage would occur, thus voiding the test sample. The participants were permitted to use whatever tools they thought were appropriate.

All connectors were assembled in an aerial mode with a tap box attached to a strand, supported between two poles. An enclosed platform simulated a bucket truck.

The .50 inch feed through connectors chosen for this program were a new improved design and two of the most popular mechanical connectors used by the industry.

The new Raychem ThermoCrimp connector system consists of an Alodine-600 coated aluminum connector body and a molded high recovery force polymer (HRFP) crimp ring coated with a temperature indicating paint. The connector is shown in Figure 1 before installation, before heating and after the installation is completed.

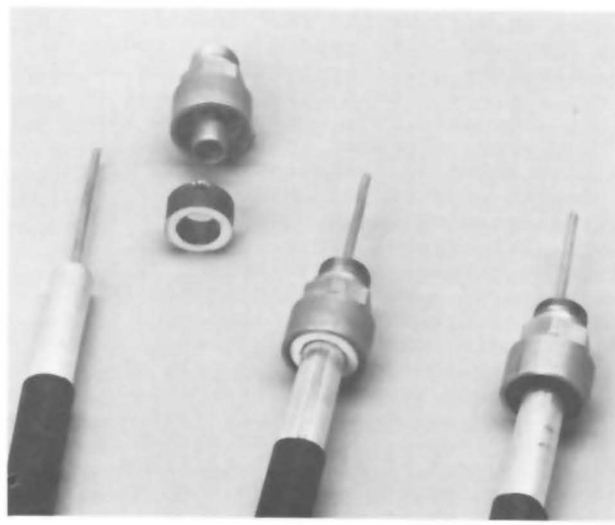

Figure 1

A properly installed connector would, in all cases, result in breakage of the cable outer sheath. An improperly installed connector would slip from the cable sheath as the load was applied.

The results of testing three different types of connectors installed by ten individuals are shown in the following tables. Failure is defined as the connector slipping from the end of the cable.

Raychem Personnel

BRAND	NUMBER OF PEOPLE	NUMBER OF PIECES	FAIL	PERCENT FAIL
Raychem	7	16	0	0
B	7	16	6	38
C	7	16	6	38

CATV Personnel

BRAND	NUMBER OF PEOPLE	NUMBER OF PIECES	FAIL	PERCENT FAIL
Raychem	3	7	0	0
B	3	7	1	15
C	3	7	1	15

The Raychem connector is significantly less craft sensitive to install. Out of a total of 23 connectors that were installed in this test program by all ten individuals, none failed.

When investigating why improper installation occurs, it was found to be due to the basic design of the mechanical connectors. That is, they employ inclined planes and threads to force a split clamping ring down against the outer conductor. This in turn is supported by the integral mandrel. The installer judges the quality of installation by feel, as to the correct installation torque. It is well known that the use of torque to indicate a good installation is poor primarily due to friction between the threads and mating surfaces. Many industries where correct preload of threaded connections is critical for proper performance utilize skilled craftsmen, friction reducing means and sophisticated torque measurement equipment to indicate proper installation.

Another problem observed with the mechnical connectors was the tendency of the expansion loop to twist as the final tightening was performed. Eliminating this tendency is difficult and awkward.

MECHNICAL TESTING

The Coaxial Connector System testing specification that was chosen to evaluate connector performance is based upon similar specifications that are used by both the telephone and electrical utility industries to predict their product lifetimes.

It is well known that the prime load carrying member of a coaxial cable is the outer conductor. Axially loading a sample of the outer conductor of a typical .50 inch diameter coaxial cable resulted in failure at approximately 490 pounds, as shown in Figure 2.

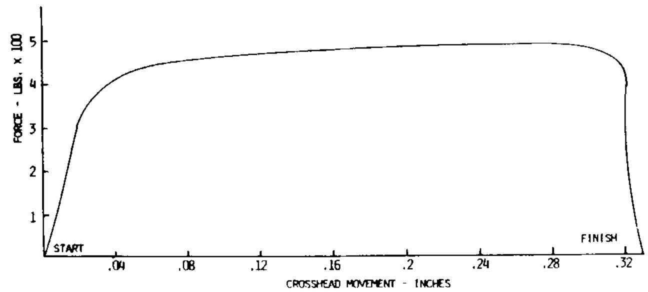

FIGURE 2

Additionally, the .110 inch diameter inner conductor will fail at approximately 190 pounds. In fact, due to the damage caused by tightening the tap box set screw, it will fail at a load of approximately 140 pounds. Perhaps of more importance is the reduction in elongation from 6.0 percent down to 2.4 percent caused by the set screw acting as a stress riser, as shown in Figure 3.

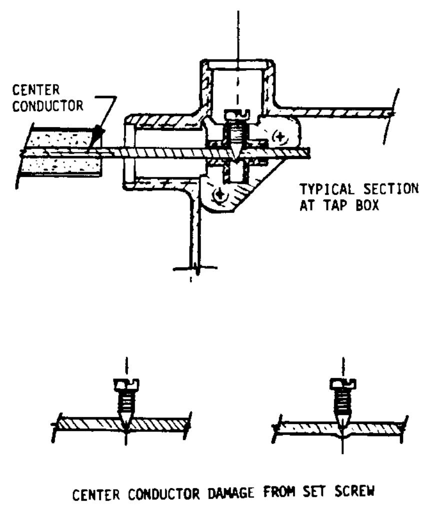

FIGURE 3

This means that with an improperly installed connector, as shown in Figure 4, in which the outer conductor is not tightly gripped, any small amount of axial movement can result in breakage of the center conductor.

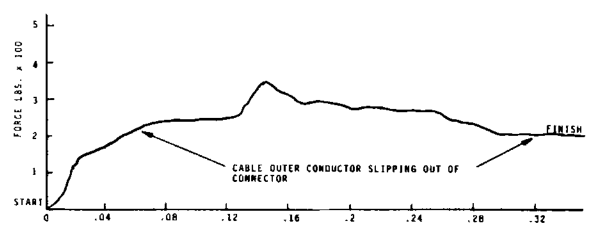

FIGURE 4

The assumption was made, therefore, that all of the environmentally induced loads must be carried by the cable outer conductor. The environmental loads imposed on the coaxial cable system are tension caused by temperature changes and ice loading, along with vibration effects caused by the wind. These loads may act alone or in combination with each other.

For a typical .50 inch diameter coaxial cable most manufacturers recommend a maximum pulling force of 200 pounds to prevent damage to the cable during installation. Our preliminary testing using mechnical connectors showed that for improperly installed connectors slippage of the outer conductor from the connector was initiated at loads as low as 200 pounds. After some movement, the load would approach 400 pounds prior to the cable pulling out of the connector. The amount of slippage observed would easily cause breakage of the center conductor.

Our testing also shows that in every case a properly installed connector would result in failure of the cable sheath when loaded in tension.

For the .50 inch diameter coaxial cable that was used, the test load was derived as follows:

The outer sheath has a tensile yield strength of F_{ty} = 10,000 psi

The cross sectional area of a typical .50 inch outside diameter cable with a .025 inch thick wall = $0.0373 in^2$

The axial load carrying capability at yield is given by the equation,

$$P = F_{ty} \times A = 373 \text{ pounds} \quad (1)$$

Initial testing with a sustained load of this magnitude indicated that failure of the outer sheath would occur if the load was maintained. Good engineering judgement suggested a reduction of the load at yield by 20 percent would be appropriate to serve as the test load, or

$$P_{test} = .8 \times 373 = 300 \text{ pounds.} \quad (2)$$

Since it is possible to install a coaxial connector in a manner that will allow the passing of the axial load requirement, but still allow the connector to rotate with respect to the cable, an installed connector torsion test was devised. Again, using a .50 inch diameter cable, samples were tested in an Instron to determine the amount of torque required to yield the cable outer conductor. This was found to be 58 inch-pounds.

The test recommended is to apply a torsional load of 50 inch-pounds (a small amount below the yield point) before and after the environmental cycling test. The environmental cycling test employed is similar to ones used by utility companies to evaluate component materials and can predict life times in excess of thirty years, see Figure 5.

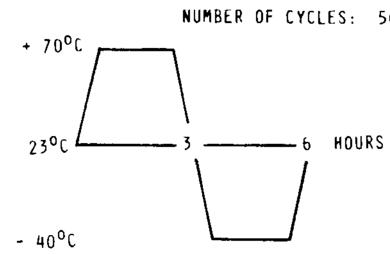

FIGURE 5

Other tests were axial shock and bending to simulate in an accelerated manner the effects of wind loading.

The following is the final proposed test program for .50 inch diameter coaxial cable. The necessary test loads for any other sizes can be easily determined.

Axial Tension Test

Axial Tension Test was performed as follows: Cable samples prepared with connectors on each end shall be loaded in tension with the force specified below for a period of 6 hours at -40°C.

CABLE SIZE	AXIAL LOAD
500	300 + 5 Pounds

Thermal Aging

Thermal Aging was conducted as follows: Cable samples prepared with connectors on each end shall be loaded in tension with the force specified below. The samples shall be placed in an air circulating oven at 70°C with an air velocity of 30 to 60 meters per minute for a period of 168 hours.

CABLE SIZE	AXIAL LOAD
500	300 + 5 Pounds

Axial Shock Loading

Axial Shock Loading testing was performed as follows: Cable samples prepared with connectors on each end shall have the axial impulse load shown below, applied at a rate of one cycle per second for a period of 6 hours at both -40 and +70°C.

CABLE SIZE	AXIAL LOAD
500	300 + 5 Pounds

Environmental Cycling

Environmental Cycling was performed as follows: Cable samples prepared with connectors on each end shall be loaded in tension with the axial loads shown below and environmentally cycled. Cycling consists of 50 continuous cycles of -40°C, +70°C and -40°C. The cycle shall run 6 hours. Each cycle shall consist of 2 hours at

+70°C and -40°C. The transition time between the high and low temperature limit is 1 hour.

CABLE SIZE	AXIAL LOAD
500	300 + 5 Pounds

Torsion Testing

Torsion Testing the cable samples from the environmental cycling test shall be subjected to the torque values shown below at 70°C before and after the environmental cycling.

CABLE SIZE	TORSION LOAD
500	50 + 1 Inch-Pounds

Bend Testing

Bend Testing was performed with the cable specimens prepared with connectors on both ends. They shall have a cyclic bending force appled to the cable. The test consists of multiplanar bending achieved by fixing one end of the specimen and rotating the other end around the cable axis while simultaneously applying the axial load shown below. The test duration is 4 hours at a loading rate of one cycle per second. One end of nine inch cable specimen is displaced from the cable axis by 0.10 inches.

CABLE SIZE	AXIAL LOAD
500	300 ± 5 Pounds

Flexure Testing

Flexure Testing of the cable samples was performed as follows: A five foot long cable sample is prepared by forming two smooth bends into the cable to make an eight inch displacement in the cable axis. The sample with connectors on each end is then tested to failure by fixing one connector and displacing the other connector 1.5 inches in the axial direction.

Water Seal

Water Seal testing was performed in order to evaluate the water seal between the cable and the connector. Samples of installed connectors were subjected to a three foot external waterhead and monitored for leakage.

Pressure Seal

Pressure Seal testing was performed as follows: Samples of installed connectors are pressurized with air to a pressure of 60 psi. The sample passes if it retains pressure for 4 hours. Pressure loss is detected by water submersion and the presence of bubbles.

SAMPLE PREPARATION

Based on the craft sensitivity testing and reports from the cable system operators on cables pulling out of connectors, we prepared one half of all the cable samples with controlled mis-installed connectors, as well as correctly installed connectors. The correct and incorrect installation of each connector was performed as follows. For each test we used equal numbers of correctly and incorrectly installed connectors.

Raychem ThermoCrimp

The correct installation of the Raychem ThermoCrimp is determined by complete conversion of the thermochromic paint from white to black. For the incorrect installation we only converted one half the paint.

Connector B

Connector B's correct installation of torque was a minimum of 25 foot-pounds of torque. The incorrect installation was 11 foot-pounds of torque.

Connector C

Connector C's correct installation was a minimum of 14 foot-pounds of torque. The incorrect installation was 8 foot-pounds.

TEST RESULTS

Axial Tension	Pass	Fail
Raychem ThermoCrimp	16	0
Connector B	14	0
Connector C	11	1

Thermal Aging	Pass	Fail
Raychem ThermoCrimp	16	0
Connector B	14	0
Connector C	11	1

Axial Shock Loading	Pass	Fail
Raychem ThermoCrimp	24	0
Connector B	24	0
Connector C	20	4

Environmental Cycling	Pass	Fail
Raychem ThermoCrimp	32	0
Connector B	24	0
Connector C	18	6

Torsion Test	Pass	Fail
Raychem ThermoCrimp	32	0
Connector B	24	0
Connector C	18	6

Bending Test	Pass	Fail
Raychem ThermoCrimp	16	0
Connector B	16	0
Connector C	16	0

Flexure Test	Pass	Fail
Raychem ThermoCrimp	12	0
Connector B	12	0
Connector C	12	0

Water Seal Test	Pass	Fail
Raychem ThermoCrimp	12	0
Connector B	12	0
Connector C	12	0

Pressure Seal	Pass	Fail
Raychem ThermoCrimp	10	0
Connector B	10	0
Connector C	10	0

CONCLUSIONS

1. Any coaxial connector that utilizes chucks, inclined planes, and screw threads to properly clamp the coaxial cable appears to be more craft sensitive to install than the ThermoCrimp connector.

2. The flexure test did not result in any failure adjacent to the connector, but did cause cable outer sheath breakage in the bends. These cracks, which for jacketed cable cannot be seen, can easily cause signal ingress or egress problems.

3. The center conductor gripping device used in amplifier housings and passive devices seriously weakens the center conductor.

4. Two of the test parameters, craft sensitivity and environmental cycling, appear to be the most descriminating as a means of evaluating connector mechanical performance.

5. We also found out that any connector should not be reused or used as a union. The gripping mechanism in the mechanical connectors, if correctly installed, put circumferencial scratches in the cable's outer conductor. The result is, if disconnected and then reinstalled, a weakening of the cable axial load carrying capability due to the scratches.

REFERENCES

1 E. Winston, "Stress Analysis of CATV Aluminum-Sheathed Cables Lashed to Hanging Steel Strand", IEEE Transactions on Cable Television, Volume CATV-1, No. 1, October 1976.

2 Brad Kellar, "Standardized Return Loss Measurement of Cable Television Distribution Connectors", 32nd Annual NCTA Convention Technical Papers, 1983.