**MECHANICAL AND CRYOGENIC TESTING
OF VLPC FLEX CIRCUITS
MADE BY
LITCHFIELD, CIREXX, AND SPEEDY CIRCUIT**

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Mechanical and Cryogenic testing of recent Flex Circuits

for the VLPC cassette

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Four flex circuits were tested. They are categorized as:

1. Litchfield narrow
2. Litchfield wide
3. Cirexx wide
4. Speedy Circuit green

Description of the flex circuits:

1. Litchfield narrow: This flex circuit has been at Fermilab for more than a year. It was put into a test cassette at one time. The acrylic/urethane/imide coverlay (DuPont pyralux PC1020) was seen to be cracking badly at the backside of the bend at the cold end. The coverlay film is vacuum laminated onto the base circuit with mechanical pressure plus some heating. It was version VLPC_G.
2. Litchfield wide: This flex was the next generation of the Litchfield narrow. The width of the flex was increased and the interspersed traces between channels were removed. This flex circuit also had been in a test cassette at one time. It has an acrylic/urethane/imide coverlay DuPont PC 1520. The tested circuit was version V64C.
3. Cirexx wide: New mechanical sample just received from a possible vendor. The coverlay is 1/2 mil polyimide bonded to the base circuit with 1/2 mil of acrylic adhesive.
4. Speedy circuit green: New mechanical sample received from a possible vendor. The coverlay is a liquid photoimageable covercoat, Rogers Corporation type 8080 LP1. (It has no adhesive layer.)

Test Results summary:

The cross sectional area of copper was calculated from trace resistance measurements. All the flex circuits had an acceptable amount of copper cross section, about $6 \times 10^{-8} \text{ m}^2$ for all except the Cirexx flex which had $4.5 \times 10^{-8} \text{ m}^2$. The thickness of the ribbons was 0.006" for the Litchfield and about 0.004" for the Cirexx and Speed circuit.

The room temperature resistivity ratio (RRR) was measured to be 15 for all the circuits. This was expected and means that the trace material resistivity at helium temperatures is $1/15^{\text{th}}$ of what it is at room temperature. This is good from the standpoint of thermal heat load. Purer copper, with an $\text{RRR} > 30$ would result in an unacceptable heat load.

The cryogenic cycling and bending tests to liquid nitrogen proved that both the Cirexx wide and Speedy circuit green were made of acceptable materials. Both Litchfield flex circuits had significant cracking of the coverlay when bent at cold temperatures and are not acceptable.

Conclusions of tests:

The **Litchfield narrow** was in bad physical condition to start with and got worse through the testing with many more crazing cracks appearing. The crazing is bad enough that the coverlay began to peel and expose the copper beneath. This candidate is unacceptable.

The **Litchfield wide** started out testing in good condition with no cracks. It ended up with much crazing in the coverlay. Within 1 mm of the edge of the coverlay at the cold end, the copper traces were bulged away from the base material. Traces became adhered and lifted off of the base material at the ends where the coverlay was not present. Numerous electrical opens (7 out of 24 checked) were found at the end of the testing. Visual inspection of the opens leaves open the possibility that the traces are broken below the coverlay in the cold bend area. Obviously this candidate is unacceptable.

The **Cirexx wide** was a mechanical sample with no promises made about its electrical integrity, however of the traces checked all were fine after the brutal testing. This flex circuit appears suitable for the intended cryogenic and mechanical environment. See recommendations for ideas on how to make it better.

The Speedy circuit came out as acceptable in the testing also. The material remained flexible at cryogenic temperatures. 2 out of 24 traces were found open after the testing, but this was a mechanical sample and those traces were not checked beforehand so it is unknown if the testing caused the opens or they were there at the start. This sample was not presented as having final product electrical characteristics. See recommendations for ideas on how to make it better.

Recommendations:

Cirexx wide:

The flex circuit could be manufactured in a cleaner environment to eliminate foreign matter being included under the coverlay and indentions being present on the coverlay surface. It is possible that the effects of such foreign matter could locally cause a failure of the traces and/or delamination of the coverlay. The indentation marks, taken to an extreme could also cause a trace to be broken.

The PS01 cryo sensor trace is just about cut off from the circuit at the rectangular connector pad location. The trace or the cut size should be changed to prevent the possibility of the trace being open.

Stop the traces at the connector pads. Extending them to the edge of the flex circuit prevents the coverlay from sealing as effectively along the edges.

Speedy Circuit:

The coverlay should be extended to the ends over the pad connection area to eliminate the problem of the traces losing adherence to the base material and possible opens from this.

Try to improve the coverlay so pock marks are not present.

— Stop the traces at the connector pads. Extending them to the edge of the flex circuit prevents the coverlay from sealing as effectively along the edges.

Details of the testing

All four flex circuits were subjected to the same testing. The testing and observations are chronologically summarized as follows:

TEST 1: The room temperature resistance of two traces in series were made. Connection to the traces were made with alligator clips which tended to impart a little creasing. The wired circuits were dunked in liquid nitrogen and while still submerged, their resistance was measured. The measured resistance dropped by a factor of 5 to 6 from the room temperature values. The resistance of pure copper drops by a factor of 12 whereas an alloys such as beryllium copper (98%Cu, 2% Be) drops only by a factor of 1.3. The traces are probably 99.9 % copper.

The flex circuits were put into the four cassette cryostat and cooled to less than 8 Kelvin. Resistance measurements were taken during the cooling. The RRR for all circuits was found to 15.

The flex circuits were warmed and visually inspected. They were then dunked in a liquid nitrogen bath twice during which it was observed that all the flex circuits remained somewhat flexible. The circuits waved similar to what one would expect of them if they were in room temperature water instead.

The flex circuits were then inspected at a magnification of four.

First careful physical observations after TEST 1:

Litchfield narrow: Extensive crazing at the ground plane side cold end.

— Litchfield wide: Traces look thicker at the first ¼" under the coverlay at the warm end. Possibly from the pad thickness build up operation? No crazing seen.

Cirexx wide: No delamination, no cracking, no bubbles. Edges are adhered. Coverlay has a "matte" finish. Some scratched areas are present probably from sliding the circuit across a table. I classify the marks as scratches due to their straight pattern as opposed to the curvy spider web pattern seen from crazing. There are two inclusions of foreign matter under the coverlay about a mm or so in size. There are a few impressions on the coverlay probably made by foreign objects during the rolling or pressing on of the coverlay. One of the pads has a copper appearance and looks like it is missing the gold plating.

Speedy circuit: No delamination, no cracking, no bubbles. Edges are dulled. Surface of coverlay is glossy. Smooth. There are occasional pock marks on the coverlay, but an electrical connection to the copper traces below can't be made at the pock marks.

TEST 2: The flex circuits were then all wrapped around a 1/2" diameter tube, ends fastened with Kapton tape. They were dunked in liquid nitrogen, warmed to room temperature, dunked to liquid nitrogen, warmed, and then looked at.

Second careful physical observation after TEST 2 (wrapped and dunk in LN2):

Litchfield narrow: New crazing now seen on both the ground plane side and channel side, cold end and warm end of the circuit. More pronounced over the solid copper ground plane areas.

Litchfield wide: Not looked at.

Cirexx wide: No problems observed.

Speedy circuit: Some surface scratches noted, no problems observed.

TEST 3: The flex circuits were then taped and wrapped in the same direction on the tube and left in the liquid nitrogen overnight. The liquid nitrogen was boiled away in the morning, I estimate they were submerged for more than 2 hours.

Third careful physical observation, after TEST 3 (extended dunk in LN2):

Litchfield narrow: Crazing has gotten worse. Spider web patterns seen to originate from holes at cold end. Crazing seen in areas not over solid copper ground plane.

Litchfield wide: Crazing on the ground plane (tension) side at cold end. Crazing clearly seen along the cryogenic sensor lead flag. Cracks there are perpendicular to the trace and are spaced every 4 mm or so. Crazing also originates from puncture indentation caused by alligator clip used during electrical tests. Trace segment seen missing on channels 33 & 34 for about 1 to 2 mm right before trace goes under the coverlay. May have been pulled off by removing Kapton tape that held it onto tube.

Cirexx wide: No problems observed. Very small edge defect, possibly delamination, 0.5 mm x 1.5 mm along cryo trace edge near warm end. May have been there before, can't peel coverlay or see crack at edge, very minor.

Speedy circuit: No problems observed.

TEST 4: Flex circuits were wrapped onto the 1/2" OD tube in the reverse direction, that is ground plane side in compression from the bend and signal trace side in tension from the bend. Kapton tape holds each end tight. The circuits and tube were submerged in liquid nitrogen long enough to reach temperature equilibrium and then pulled out and warmed to room temperature. Warming was by ambient surroundings or by some assistance of a non-warmed air flow. The circuits were temperature cycled ten times.

Fourth careful physical observation, after TEST 4 (10 cycles wrapped and dunked in LN2):

Litchfield narrow: More crazing.

Litchfield wide: Additional crazing on the cryogenic sensor lead flag. Traces lifting off of the base material at the warm end where no coverlay is present, especially between the pad and end of the flex. Traces at cold end all bulged up where the traces go under the coverlay. These segments are very susceptible to getting snagged or torn off.

Cirexx wide: A small area 2" from the warm end, cryo trace side observed from the ground plane side appears to have small cracks a few mm long initiating from a puncture indentation. The coverlay looks like it is indented, but doesn't appear to have the cracks. They may be in the base material. No other problems observed.

Speedy circuit: Ground plane side coverlay has some scratches on it. These are in a straight direction and are probably not crazing. On the signal trace side, 4" from the cold end there are some 3/8" long scratches that could be crazing. On the signal trace side, 6 1/2" from the warm end, cryo trace side a 3 mm inclusion or small bubble is seen. May have been there before. No other problems observed.

TEST 5: The circuits were now one at a time, submerged in liquid nitrogen and then bent using a stainless steel tweezer (also at liquid nitrogen temperature.) The bend was made 1 1/2" from the cold end. The radius of the bend is 3/16" +/- 1/16". The Cirexx and Speedy Circuit were subjected to this test twice. The second time about 5 pounds of tension was on the cable during the bending.

Fifth careful physical observation during and after TEST 5 (cold bend test):

Litchfield narrow: Lots of cracking heard while bending it. A multitude of cracks are observed on the tension side at the bend

Litchfield wide: Lots of cracking heard while bending. A multitude of cracks are observed at the bend.

Cirexx wide: First bending, no cracking heard and no cracks seen! Second test with tension, a few cracking noises are heard. Small cracks are barely visible at the bend.

Speedy circuit: First bending, no cracking heard and no cracks seen! Second test with tension, a few cracking noises are heard. Small cracks that look like scuff marks are visible at the bend. Test is repeated a little further up the flex and scuff type marks are seen there.

TEST 6: Electrical continuity checks on 24 traces across flex, after all tests:

Litchfield narrow: 2 out of 24 are opens. One is channel 32 which is missing a trace segment. The other is channel 54, no obvious open seen. Bias resistance okay at 1.0 ohms. (Meter has offset of 0.3 ohms)

Litchfield wide: 7 out of 24 traces are bad. 4 of them are opens (channels 22,34,45,65), 3 are flaky (channels 42,52,84) with resistance readings that vary from 600 ohms and 2000 ohms depending on movement of the cable. Since this circuit was once in a cassette, the electrical integrity was probably once good. Not any more. Bias resistance okay at 0.6 ohms.

Cirexx wide: All 18 out of 18 traces are good. The other 6 traces that would have been checked are cut off by Cirexx to indicate that this is a mechanical sample. Bias resistance okay at 1.0 ohms.

Speedy circuit: 2 out of 24 traces are bad. Channel 25 and 15 are open. The suspect location for the opens cannot be seen at four times magnification. Bias resistance okay at 0.5 ohms.

Resistivity of Flex traces

	Litchfield Narrow Ch 24 and 82	Litchfield Wide Ch 24 and 82	Cirexx Widest Ch 32 and 45	Speedy Glass Ch 24 and 82
Resistance (Ohms) at 293 K	45.13	26.54	53.56	40.51
Resistance (Ohms) at 78 K	7.61	5.13	10.31	6.31
Resistance (Ohms) at 293 K	44.51	26.03	53.12	39.87
Resistance (Ohms) at 150 K	20.50	16.09	26.42	15.34
Resistance (Ohms) at 77 K		6.90		11.36
Resistance (Ohms) at 8 K	2.62	1.28		3.60
Resistance (Ohms) at 293 K	45.16	26.56	54.52	39.00
Resistance(293 K)				
Resistance(78 K)	5.89	5.12	5.17	6.37
Length (inches) Middle Pad to Middle Pad	18.625	16.4375	15	15
# Channel Traces	64	64	64	64
# Bias Traces	64	64	64	64
# Cryo Traces	8	8	8	8
# Interspersed Traces	63	0	62	62
Mid-Trace Width (in.)	0	0	0.005	0.005
Area of Cu (m^2)	6.51E-08	6.70E-08	4.45E-08	5.88E-08
Thickness of ribbon (in.)	0.0062	0.0057	0.00433	0.00383
Average width of ribbon (in.)	0.84375	1.3125	1.6094	1.34375
Area of ribbon (m^2)	3.37E-06	4.83E-06	4.50E-06	3.32E-06
Ratio, Area ribbon/Area Cu	52	72	101	56

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64% REDUCED COPY OF SAMPLES

FOLDED OVER TO FIT WITHIN IMAGE WINDOW

LITCHFIELD NARROW

LITCH FIELD WIDE

CIREXX

SPEEDY CIRCUIT