CABLE FABRICATION PROCEDURES FOR THE BPM SYSTEM*

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The Beam Position Monitor (BPM) System is a critical component of beam steering and control. It consists of the Beam Position Monitors (in the beamline), electronic signal processors (located remotely) and the cables that interconnect the two.

Each BPM produces four signals. These four signals are then compared electronically with each other. Differences in amplitude among these signals is converted into information about the position of the beam as it passed that particular BPM.

In order to provide the needed accuracy for this system, all four signals from each BPM must arrive at the processing electronics simultaneously. This means the interconnecting cables must be matched very precisely. The following procedures, when followed precisely, will assure the matching of BPM cables.

TOLERANCE STANDARDS: We use RG223/U coaxial cable for the BPM System. The manufacturer specifies its propagation velocity is 1.54 nS/ft. For the BPM electronics to operate accurately, each of the four signals from a single BPM must arrive at the electronics within 0.5 nS. And since cable runs range from 100 to 300 feet, this requires an accuracy of 3.0 inches or 0.3% (or better)!

THE PROBLEM: Conventional cable measurement/cutting techniques produce typical accuracies on the order of 1%, far too coarse for the BPM System. Hence, the more sophisticated technique that follows.

THE TIME DOMAIN REFLECTOMETER (TDR): This is a marvelously sensitive instrument. When properly calibrated, it is also extremely accurate. Phase I describes the procedure to be followed to calibrate the instrument. All subsequent work is highly dependent upon the care you give this calibration.

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PHASE I, TDR CALIBRATION

- Step 1:** Interconnect the various instruments as shown on the attached Test System Interconnection Diagram.
- Step 2:** Turn on all electronic equipment. Allow at least $\frac{1}{2}$ hour for warm-up, longer if at all possible.
- Step 3:** Measure PRECISELY and cut one RG223/U cable. Make its length equal to or greater than the maximum length of the sets of cables to be made. Actual cable length should be selected in order to facilitate fabrication and operator preference. Terminate one end of the cable with SMA connector. Leave the other end open.
- Step 4:** Repeat Step 3, only this time make the cable length EXACTLY one-half the length of the first cable. PRECISION is the key to Steps 2, 3 and 4. Any errors here will lead to greater inaccuracies in the BPM cables to be fabricated. The cables made in Step 2 and Step 4, along with a "zero-length" (i.e. no cable) comprise a three-point calibration system for the TDR.
- Step 5:** Set the SPDT coaxial switch "A" to "TDR Mode". Set the TDR "V/DIV" dial to 0.05. Set the DP4T coaxial switch "B" to position "1". Set "Function" to "VAR" mode. Set "SCAN" to "Normal". Set "PERSISTENCE" to "NORMAL" mode. Set "DISPLAY" to "INTERNAL". Set "MAGNIFIER" to "X1". And set "MARKER POSITION" (Div) to "TIMES 100" and expand to 1 ft/div.
- Step 6:** Find the leading edge of the reflected pulse on the TDR's CRT display. This will appear as an abrupt transition in the trace from a horizontal one to one that rises steeply. We will use the "knee" where this transition takes place as the standard measuring point for all subsequent measurements with the TDR. The waveform will look like this:

MASTER

Step 7: Having found the reflected pulse, set the "knee" on the X-Axis 0% graticule, using a combination of the marker dial and the coarse and fine Horizontal Position adjustments. When properly done, the "knee" will sit squarely on the 0% graticule, the Marker Dial will read "000" and Switch "B" will be in position "1".

Step 8: Set the Marker Dial to the length of the longest cable (or to its nanosecond equivalent, if in the time mode). Set Switch "B" to position "2". Use a jeweler's screwdriver to adjust "VAR" so that the new "knee" falls exactly on the 0% graticule.

Step 9: The adjustments you made in steps 7 and 8 affect each other. So repeat steps 7 and 8 until you can step from one to the other without having to adjust either one.

Step 10: Set Switch "B" to position "3" and adjust the Marker Dial for the length of the shorter cable (or its nanosecond equivalent if in the time mode). The new "knee" should be very close to the 0% graticule. If not, combine Steps 8 and 10 and "rock" the calibration to the best compromise you can find. You will find that the accuracy of your cable cutting will have a major impact on the ease with which you are able to accomplish this calibration procedure.

The calibration procedure for the TDR is now complete.

**** WARNING ** WARNING ** WARNING ** WARNING ****

IT IS VERY EASY TO BUMP OTHER ADJUSTMENTS WHILE MAKING ADJUSTMENTS TO THE TDR OR WHILE WORKING WITH THE CABLES. EVEN THE SLIGHTEST BUMP WILL DESTROY THE ACCURACY. IT IS IMPERATIVE THAT YOU REPEAT THIS CALIBRATION PROCEDURE ANYTIME YOU SUSPECT THE TDR'S SETTINGS HAVE BEEN DISTURBED IN ANY WAY!

**** WARNING ** WARNING ** WARNING ** WARNING ****

THIS CALIBRATION PROCEDURE SHALL BE PERFORMED AT THE BEGINNING OF EACH DAY'S WORK AND BEFORE BEGINNING WORK ON EACH NEW SET OF FOUR BPM CABLES TO BE TRIMMED.

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PHASE II, CABLE TRIMMING

- Step 1:** Cut four cables. Make each two to four feet longer than the length prescribed. Terminate one end of each cable with an SMA connector (see attached trim code charts for details).
- Step 2:** As in the calibration procedure (Phase I), Switch "B" should have no cable attached to position "1", the shorter of the two calibration cables ($\frac{1}{2}$ the length of the longer calibration cable) to position "3". Attach one of the cables to be trimmed to position "4".
- Step 3:** Confirm TDR calibration by switching Switch "B" through the first three positions.
- Step 4:** Set the vernier scale to the desired length (length mode) or delay (time mode). Turn Switch "B" through the first three positions.
- Step 5:** Carefully "prune" the unterminated end of cable #4 until the reflected pulse's "knee" falls within ONE (1) MINOR DIVISION of the 0% graticule of the TDR's display.
- Step 6:** Disconnect the two calibration cables. Connect the three remaining cables of the set of four positions. "1", "2" and "3".
- Step 7:** Repeat Step 5 for cables 1, 2 and 3.
- Step 8:** Visually compare the four cables with the TDR by switching "B" through the four positions. **NO TWO CABLES SHOULD DIFFER BY MORE THAN 1.5 MINOR DIVISIONS ON THE TDR GRATICULE. ALWAYS TRIM CABLES #1, #2 or #3 as needed to make this match. Cable #4 is your standard now, and should NOT BE TRIMMED.**
- Step 9:** Now that the cables have been carefully trimmed, terminate the unterminated end with the appropriate connector (SMA or SHV) according to the attached trim code charts.

NOTE: If difficulty is experienced in the termination procedure and a cable must be retrimmed in order to be properly terminated, repeat Step 8. If the cable still meets the standard in Step 8, it is acceptable. If not, then a new cable must be fabricated.

PHASE III, ATTENUATION MATCHING

Mismatches in attenuation can not be remedied. Thus any cable of a four-cable set that can not meet attenuation tolerances must be discarded from the set, and a new cable fabricated to take its place. However, a longer cable discard might prove satisfactory (once properly trimmed to the new length) as a substitute for a mismatched cable of a shorter set. Hence it is recommended that the longest sets of cables be tested for attenuation matching first.

ATTENUATION STANDARD: Each cable of a four-cable set must be within 1% of each of the other three.

- Step 1:** Set Switch "B" to position "1". Connect cable #1 to Input #1. Now connect the free end of cable #1 to output #1. Observe the TDR display. The reflected pulse should disappear, confirming proper connection.
- Step 2:** Set Switch "B" to position "2". Connect cable #2 to Input #2 and output #2, in much the same fashion as in Step 1. Repeat the procedure for cables #3 and #4. Be sure to use the TDR display to confirm proper connection in each case.
- Step 3:** Set SPDT coaxial Switch "A" to "Res" position.
- Step 4:** Using the oscilloscope, adjust the DELAY GATE GENERATOR (DGG) so that its output overlaps the leading negative pulse of the PULSE STRETCHER.
- Step 5:** Maximize this overlap by maximizing the DIGITAL VOLTMETER (DVM) reading.
- Step 6:** Step through the four positions of Switch "U", noting the DVM values for each position.
- Step 7:** Compute the deviation between the maxima and minima of the cable set. Reject any cable which exhibits a deviation greater than $\pm 0.5\%$ of the mean.

EXAMPLE: The DVM readings for a set of cables are: 610, 611, 609 and 602, respectively. The mean would be: $(610 + 611 + 609 + 602)/4$ or $2432/4 = 608$. $\pm 0.5\%$ of 608 = 3.04.

Hence allowable attenuation for this set would have to be within the span from 604.96 to 611.04. Obviously, cables #1, #2, and #3 meet this standard. But at a value of 602, cable #4 must be rejected.

Carrying this example further, the replacement for cable #4 produces a DVM reading of 614. A new mean must be calculated (611) and the acceptable $\pm 0.5\%$ span calculated (± 3.055). This new span is 607.945 to 614.055. Now all four cables are acceptable, although Cable #4 just barely makes it.

TRIM CODE CHART

SM.A CONNECTOR:

$$A = \frac{14}{32}$$

$$B = \frac{7}{32}$$

$$C = \frac{4}{32}$$

Use crimp die
KTN 2001

SHV CONNECTOR:

$$A = \frac{30}{32}$$

$$B = \frac{23}{32}$$

$$C = \frac{3}{32}$$

Use connector body
Kings # 1705-2 with
the sleeve from a
Kings # 1705-1.
Crimp first with a
KTN 2062 die and
again with a
KTN 1061 die.

BEAM POSITION MONITOR CABLE TRIM AND CALIBRATION TEST STATION INTERCONNECTION DIAGRAM

Note: 1) All cables are "BNC-RG58C/U-BNC" unless otherwise indicated.
2) Solid lines denotes cable connections.
3) Dashed lines indicate direct connections.