HUBBELL POWER SYSTEMS

OHIO BRASS

ANSI DESIGN TEST REPORT
Report No. EU1250-HR-00
Type PVI Intermediate Class
Surge Arrester

This report records the results of the design tests made on Type PVI Intermediate Class surge arresters in accordance with IEEE Standard C62.11-1999 "IEEE Standard for Metal Oxide Surge Arresters for AC Power Circuits (> 1kV)".

To the best of our knowledge and within the usual limits of testing practices, tests performed on the Type PVI arresters demonstrate full compliance with the relevant clauses of the referenced standard.

Michael G. Comber

M.G. Comber
Manager, Engineering

Dennis W. Lenk

Dennis W. Lenk P.E.
Principal Engineer

Date: 10/27/03

Separate reports provide details of the tests, according to the following table:

Report No.	Description	Clause	Issue Date
EU1250-HR-01	Insulation Withstand	8.1	10/27/03
EU1250-HR-02	Discharge Voltage	8.3	10/27/03
EU1250-HR-03	Disc Accelerated Aging	8.5	10/27/03
EU1250-HR-04	Contamination	8.7	10/27/03
EU1250-HR-05	Seal Integrity	8.8	10/27/03
EU1250-HR-06	Internal Ionization and RIV	8.9	10/27/03
EU1250-HR-07	High Current, Short Duration	8.10.1	10/27/03
EU1250-HR-08	Transmission Line Discharge	8.10.2	10/27/03
EU1250-HR-09	Duty Cycle	8.11	10/27/03
EU1250-HR-10	Temporary Overvoltage	8.12	10/27/03
EU1250-HR-11	Pressure Relief	8.13	10/27/03
EU1250-HR-12	Maximum Design Cantilever Load-Static	8.19	10/27/03
EU1250-HR-13	Thermal Equivalency Test	7.2.2	10/27/03

TYPE TEST REPORT No. EU1250-HR-01

Insulation Withstand Tests on PVI Arrester Housing

CERTIFICATION

This is to certify the insulation withstand test capability of the Ohio Brass Type PVI Intermediate Class surge arresters.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
Type PVI Intermediate Class Surge Arrester

TITLE: Arrester Insulation Withstand Tests:

OBJECTIVE: To demonstrate that the voltage withstand capability of the arrester housing external insulation meets the requirements as specified in Table 4 of IEEE C62.11-1999 Standard.

CONCLUSION: Table 1 lists PVI arrester minimum strike distance and leakage distance as well as required 1.2/50 impulse withstand, 60 Hz wet, and 60 Hz dry withstand capabilities. All PVI arrester ratings meet or exceed these required levels of withstand voltage.

Table 1

Summary Data - Insulation Withstand Test

Catalog No.	MCOV (kV_{rms})	Rated Voltage (kV_{rms})	Arrester Strike Distance (in)	Arrester Leakage Distance (in)	Required 1.2/50 Impulse Withstand (kV_c)	Required 60 HZ 1 Minute Dry W/S (kV_{rms})	Required 60 HZ 10 second Wet W/S (kV_{rms})
300003	2.55	3	9	19	60	21	20
300005	5.1	6	9	19	75	27	24
300008	7.65	9	9	19	95	35	30
300009	8.4	10	9	19	110	50	45
300010	10.2	12	9	19	110	50	45
300013	12.7	15	11.9	26	110	50	45
300015	15.3	18	11.9	26	150	70	60
300017	17	21	11.9	26	150	70	60
300020	19.5	24	17.1	40	150	70	60
300022	22	27	17.1	40	200	95	80
300024	24.4	30	17.1	40	200	95	80
300029	29	36	17.1	40	200	95	80
300031	31.5	39	22.9	54	250	120	100
300036	36.5	45	22.9	54	250	120	100
300039	39	48	22.9	54	250	120	100
300042	42	54	22.9	54	220	-	90
300048	48	60	33.3	81	254	-	104
300057	57	72	33.3	81	297	-	121
300070	70	90	44.3	109	372	-	152
300076	76	96	44.3	109	389	-	159
300084	84	108	39.3	109	440	-	180
300088	88	108	39.3	109	440	-	180
300098	98	120	66.4	162	487	-	199
300106	106	132	66.4	162	558	-	228
300115	115	144	66.4	162	584	-	239

TYPE TEST REPORT No. EU 1250-HR-02

Discharge Voltage Characteristic

CERTIFICATION

This is to certify that the discharge voltage characteristic design tests have been successfully performed on Ohio Brass Type PVI Intermediate Class surge arresters.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
Type PVI Intermediate Class Surge Arrester

TITLE: Discharge-voltage characteristic

TEST OBJECTIVE: These measurements are used to obtain the maximum discharge voltages at various current magnitudes and waveshapes.

TEST PROCEDURE: Discharge voltage tests were performed on three single disc test samples. Tests were conducted in accordance with clause 8.3 of ANSI/IEEE Standard C62.11. Test samples were subjected to 8/20 current waves with magnitudes ranging from 1.5 kA through 20 kA. In addition, Front-of-wave and switching surge discharge voltage tests were performed. c

TEST SAMPLES: Arresters are assembled from discs accumulated within 10 kA IR ranges as specified for each arrester rating. To verify catalog maximum IR levels were not exceeded, a discharge voltage ratio was established at each current level based on the test sections 10 kA IR (Table 1). That ratio was multiplied by the maximum allowed 10 kA IR accumulation specified for each rating. As summarized on Table 2, the IR calculated based on the prorated test sections do not exceed the maximum declared catalog levels.

TEST RESULTS: Figures 1-11 contain oscillograms for test section 1 at each current and wave shape.

Figure 1
500A, 10.636, 56/99 Waveshape

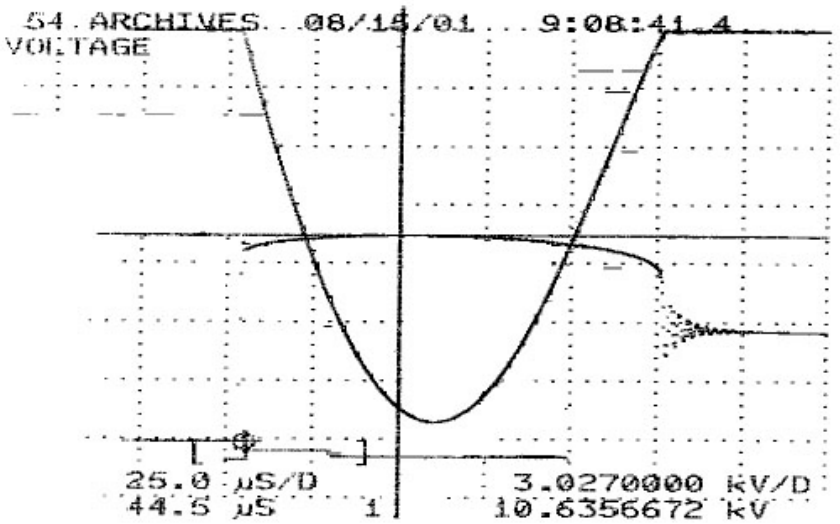


Figure 2
1 kA, 11.049kV, 56/99 Waveshape

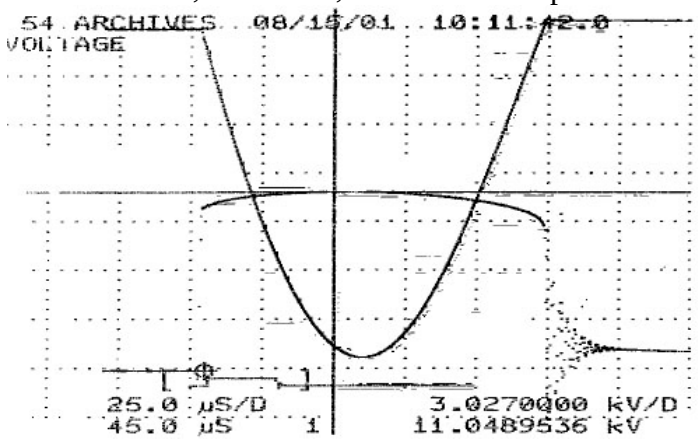


Figure 3
1.5 kA, 11.372 kV, 8.4/18.4 Waveshape

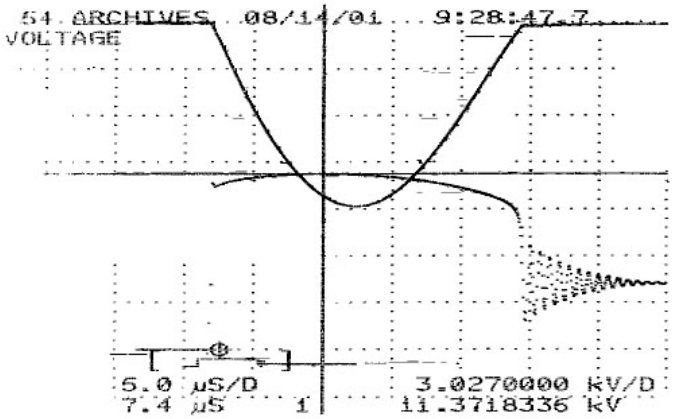


Figure 4
3 kA, 12.011 kV, 8.4/18.4 Waveshape

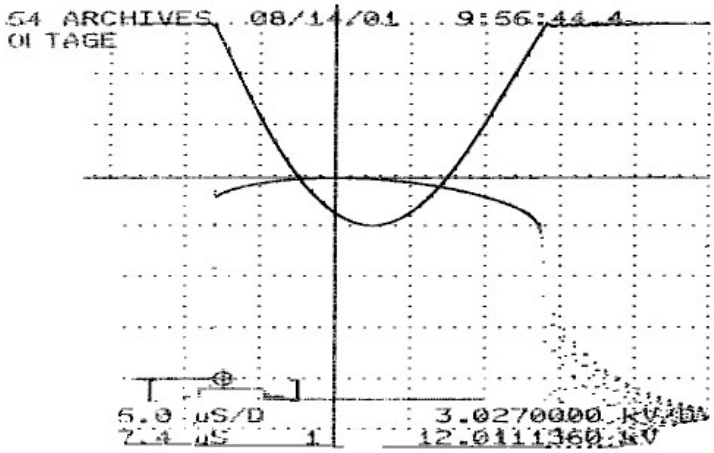


Figure 5
5 kA, 12.573 kV, 8.4/18.4 Waveshape

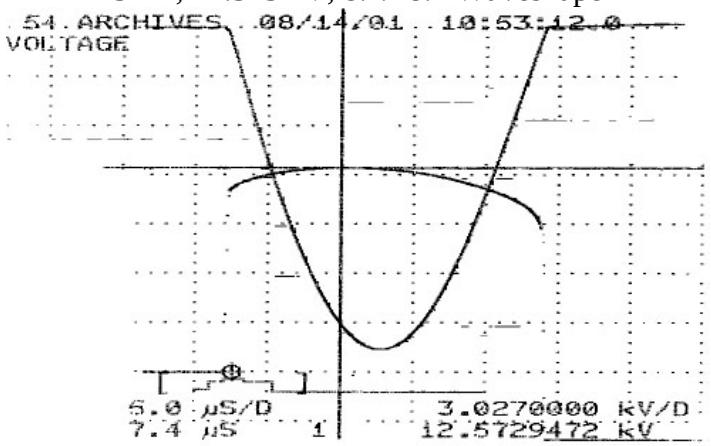


Figure 6
10 kA, 13.561 kV, 8.7/19.0 Waveshape

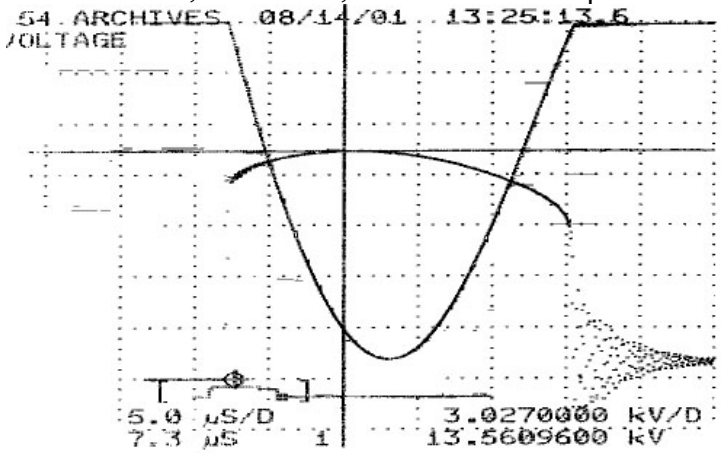


Figure 7
20 kA, 15.007 kV, 8.2/18.7 Waveshape

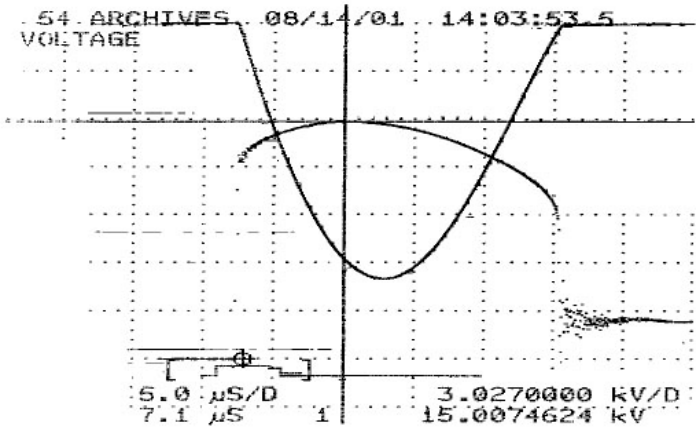


Figure 8
40 kA, 16.912 kV, 8.5/19.4 Waveshape

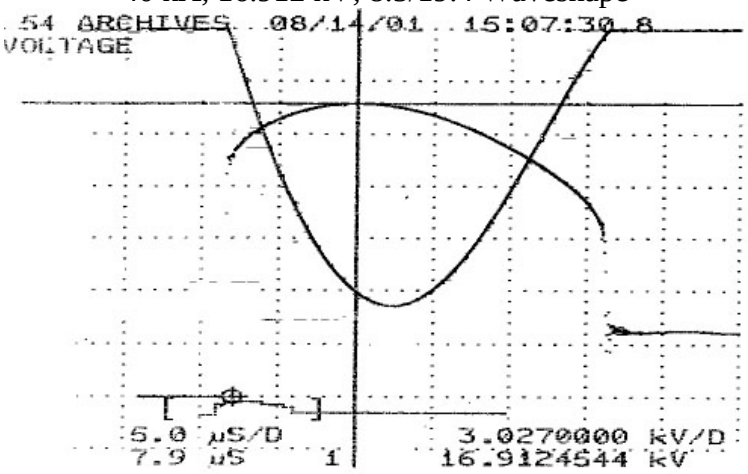


Figure 9
10 kA FOW, 13.944 kV @1.06microseconds to voltage crest

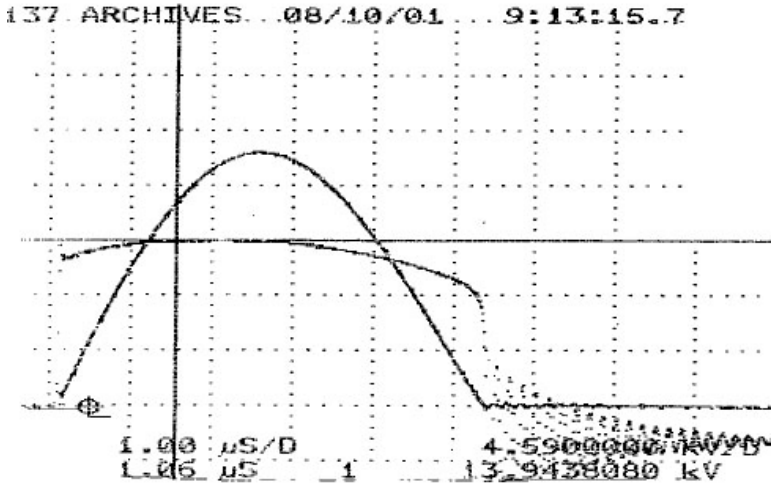


Figure 10
10 kA FOW, 14.257 kV @ .425 microseconds to voltage crest

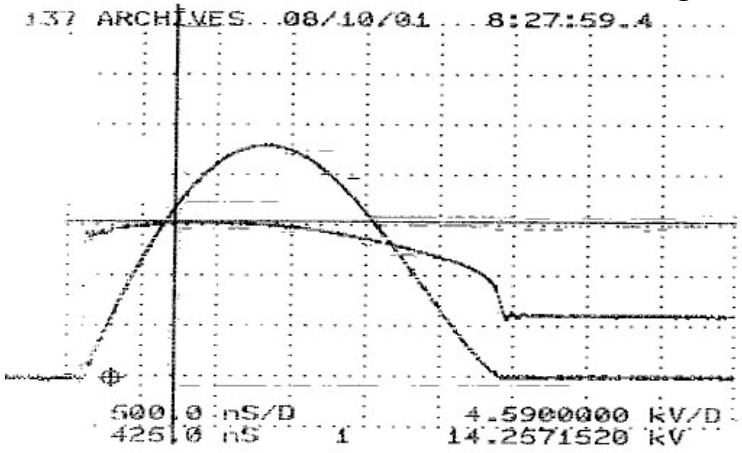


Figure 11
10 kA FOW, 14.727 kV @ .48 microseconds to voltage crest

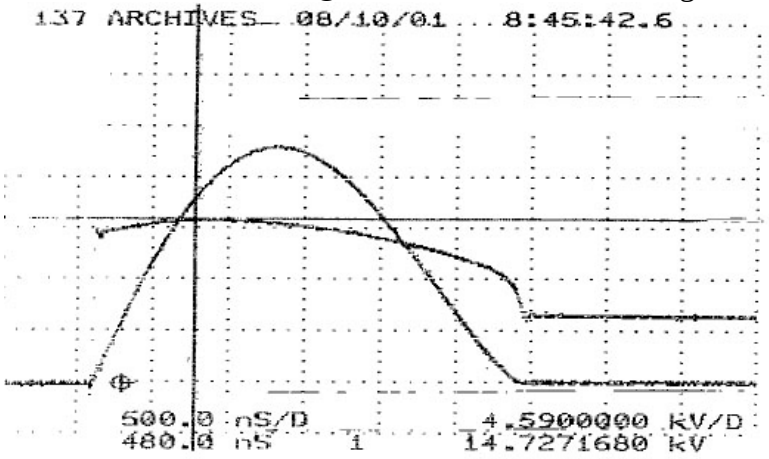


Table 1
Sample Discharge Voltage Data Summary

Impulse Current (A)	Wave Shape	Discharge Voltage (kV)			Discharge Voltage Ratio		
		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
500	60/100	10.636	10.900	10.584	0.784	0.782	0.778
1000	60/100	11.049	11.301	11.010	0.815	0.811	0.810
1,500	8/20	11.372	11.649	11.385	0.839	0.836	0.837
3,000	8/20	12.011	12.308	12.024	0.886	0.883	0.884
5,000	8/20	12.573	12.922	12.586	0.927	0.927	0.926
10,000	8/20	13.561	13.942	13.606	1.000	1.000	1.000
20,000	8/20	15.007	15.382	15.027	1.107	1.104	1.105
40,000	8/20	16.912	17.264	16.971	1.247	1.239	1.248
10,000	_	14.257	14.727	14.257	1.052	1.057	1.048
10,000	2/4	13.944	14.257	13.944	1.029	1.023	1.025
		Time to Crest Voltage (μs)					
10,000	8/20	7.300	8.200	7.900			
10,000	_	0.425	0.480	0.400			
10,000	2/4	1.060	1.080	1.140			

		IR Multipliers	0.784	0.815	0.839	0.886	0.927	1.000	1.107	1.247	1.057
		Impulse Wave	60/100	60/100	8/20	8/20	8/20	8/20	8/20	8/20	0.5usec
MCOV	Rating	I Magnitude (A)	500	1000	1500	3000	5000	10000	20000	40000	10000
2.55	3	Specimen Measured IR	6.3	6.5	6.7	7.1	7.4	8.0	8.9	10.0	8.5
		Catalog Maximum IR	6.4	6.6	6.8	7.2	7.5	8.1	9.0	10.1	8.6
5.10	6	Specimen Measured IR	12.6	13.1	13.5	14.3	14.9	16.1	17.8	20.1	17.0
		Catalog Maximum IR	12.7	13.2	13.6	14.4	15.0	16.2	17.9	20.2	17.1
7.65	9	Specimen Measured IR	19.1	19.8	20.4	21.5	22.5	24.3	26.9	30.3	25.7
		Catalog Maximum IR	19.1	19.9	20.5	21.6	22.6	24.4	27.0	30.4	25.8
8.4	10	Specimen Measured IR	21.0	21.8	22.5	23.7	24.8	26.8	29.7	33.4	28.3
		Catalog Maximum IR	21.1	21.9	22.6	23.8	24.9	26.9	29.8	33.5	28.4
10.2	12	Specimen Measured IR	25.2	26.2	27.0	28.5	29.8	32.2	35.6	40.1	34.0
		Catalog Maximum IR	25.3	26.3	27.1	28.6	29.9	32.3	35.8	40.3	34.1
12.7	15	Specimen Measured IR	31.7	32.9	33.9	35.8	37.5	40.4	44.7	50.4	42.7
		Catalog Maximum IR	31.8	33.1	34.1	36.0	37.6	40.6	44.9	50.6	42.9
15.3	18	Specimen Measured IR	38.1	39.6	40.8	43.1	45.1	48.6	53.8	60.6	51.4
		Catalog Maximum IR	38.3	39.8	40.9	43.2	45.2	48.8	54.0	60.9	51.6
17	21	Specimen Measured IR	42.0	43.7	45.0	47.5	49.7	53.6	59.3	66.8	56.6
		Catalog Maximum IR	42.2	43.8	45.1	47.7	49.9	53.8	59.6	67.1	56.9
19.5	24	Specimen Measured IR	50.1	52.1	53.7	56.7	59.3	64.0	70.8	79.7	67.6
		Catalog Maximum IR	50.6	52.6	54.2	57.2	59.9	64.6	71.5	80.6	68.3
22	27	Specimen Measured IR	56.8	59.1	60.8	64.2	67.2	72.5	80.2	90.4	76.6
		Catalog Maximum IR	57.4	59.7	61.4	64.9	67.9	73.2	81.0	91.3	77.4
24.4	30	Specimen Measured IR	60.6	63.0	64.8	68.5	71.6	77.3	85.5	96.4	81.7
		Catalog Maximum IR	63.3	65.8	67.7	71.5	74.8	80.7	89.3	101	85.3
29	36	Specimen Measured IR	73.1	76.0	78.2	82.6	86.5	93.3	103.2	116.3	98.6
		Catalog Maximum IR	73.9	76.8	79.0	83.5	87.3	94.2	104	117	100
31.5	39	Specimen Measured IR	79.6	82.8	85.2	90.0	94.2	101.6	112.4	126.7	107.4
		Catalog Maximum IR	80.4	83.6	86.1	90.9	95.1	102.6	113.6	127.9	108.4
36.5	45	Specimen Measured IR	91.9	95.5	98.3	103.9	108.7	117.2	129.8	146.2	123.9
		Catalog Maximum IR	92.8	96.5	99.3	104.9	109.8	118.4	131.1	147.6	125.1
39.0	48	Specimen Measured IR	96.1	99.9	102.8	108.6	113.6	122.6	135.7	152.8	129.5
		Catalog Maximum IR	97.1	100.9	103.9	109.7	114.8	123.8	137.0	154.4	130.9
42	54	Specimen Measured IR	108.6	112.9	116.2	122.7	128.4	138.5	153.3	172.7	146.4
		Catalog Maximum IR	109.8	114.1	117.5	124.0	129.8	140.0	155.0	174.6	148.0
48.0	60	Specimen Measured IR	122.5	127.3	131.1	138.4	144.8	156.2	172.9	194.8	165.1
		Catalog Maximum IR	126.5	131.5	135.4	143.0	149.6	161.4	178.7	201	170.6
57	72	Specimen Measured IR	146.2	152.0	156.5	165.2	172.9	186.5	206.5	232.6	197.1
		Catalog Maximum IR	147.7	153.5	158.1	166.9	174.6	188.4	209	235	199
70	90	Specimen Measured IR	183.8	191.1	196.7	207.7	217.3	234.4	259.5	292.3	247.8
		Catalog Maximum IR	185.7	193.0	198.7	209.8	219.5	236.8	262	295	250
76.0	96	Specimen Measured IR	192.2	199.8	205.7	217.2	227.2	245.1	271.3	305.7	259.1
		Catalog Maximum IR	194.1	201.8	207.7	219.4	229.5	247.6	274.1	308.8	261.7
84.0	108	Specimen Measured IR	217.2	225.8	232.5	245.5	256.9	277.1	280.0	345.5	292.9
		Catalog Maximum IR	219.5	228.2	234.9	248.1	259.6	280.0	310.0	349.2	296.0
88.0	108	Specimen Measured IR	217.2	225.8	232.5	245.5	256.9	277.1	306.7	345.5	292.9
		Catalog Maximum IR	219.5	228.2	234.9	248.1	259.6	280.0	310.0	349.2	296.0
98	120	Specimen Measured IR	240.6	250.1	257.5	271.9	284.5	306.9	339.7	382.7	324.4
		Catalog Maximum IR	243.2	252.8	260.3	274.8	287.6	310.2	343.4	386.8	327.9
106.0	132	Specimen Measured IR	275.7	286.6	295.0	311.6	326.0	351.7	389.3	438.5	371.7
		Catalog Maximum IR	278.5	289.5	298.0	314.7	329.3	355.2	393.2	443	375.4

115	144	Specimen Measured IR	**288.3**	**299.7**	**308.5**	**325.8**	**340.8**	367.7	**407.0**	**458.5**	**388.6**
		Catalog Maximum IR	**291.2**	**302.7**	**311.6**	**329.1**	**344.3**	**371.4**	**411**	**463**	**393**

TYPE TEST REPORT No. EU1250-HR-03

Disc Accelerated Aging

CERTIFICATION

This is to certify that the disc accelerated aging design tests have been successfully performed on Ohio Brass Type PVI Intermediate Class Surge arresters.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Accelerated aging procedure

TEST OBJECTIVE: Tests were performed to measure MOV disc aging characteristics. Measured watts values are used to develop elevated voltage ratios k_c and k_r for use in determination of proratio factor of duty cycle and discharge current withstand test samples.

TEST SAMPLES: Three arrester modules were prepared. The (3) modules consisted of the longest 50 mm diameter MOV disc , spring, end terminals, barrier film and fiberglass/epoxy wrap using standard module construction.

TEST PROCEDURE: Tests were performed per Section 8.5 of ANSI/IEEE C62.11 Standard. Samples were placed inside a 115 °C ±2 °C. oven and energized at MCOV for 1,000 hours. As with the durability tests, MCOV and rated test voltages were prorated to design limits based on 7 ma Vref.

TEST RESULTS: Watts loss for each sample was recorded at MCOV and duty cycle rated voltage two hours after energization and at the completion of the 1000 hour test duration. The following table summarizes test data.

Accelerated aging test data

Sample Number	Watts Loss at 2 Hr @MCOV P_{1c} (w)	Watts Loss at 1000 Hr @MCOV P_{2c} (w)	Watts Loss at 2 Hr @Rating P_{1r} (w)	Watts Loss at 1000 Hr @Rating P_{2r} (w)	Elevation K_c	Factors K_r
1	3.67	2.23	8.18	6.59	1.0	1.0
2	3.54	2.19	8.64	6.84	1.0	1.0
3	3.54	2.00	8.88	7.06	1.0	1.0

CONCLUSION: Each test sample demonstrated decreasing watts loss at MCOV. The watts loss at rating also declined. Therefore, K_c and K_r factors equal 1.0.

TYPE TEST REPORT No. EU1250-HR-04

Contamination Test

CERTIFICATION

This is to certify that the contamination design test has been successfully performed on Ohio Brass Type PVI Intermediate Class surge arresters.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Contamination tests:

TEST SAMPLE: Tests were performed in accordance with clause 8.7 of IEEE Standard C62.11-1999 on the highest rated arrester (144 kV).

TEST PROCEDURE: Contaminant was prepared per clause 8.7.2.2 and the test procedure run per clause 8.7.2.3. The arrester was energized at MCOV for 1 hour prior to application of the slurry mixture. The arrester watts loss was measured throughout the test to monitor thermal stability.

Immediately following the 1 hour preheat, slurry was applied to the bottom half of the arrester. Within 3 minutes, MCOV was applied and watts loss measured for 15 minutes. At the end of this 15 minute test, the arrester was de-energized and the second slurry coating was applied. The arrester was then energized for an additional 15 minutes. At the end of this second 15 minute test, the arrester was maintained at MCOV until thermal stability was demonstrated.

TEST RESULTS: The 144 kV rated arrester successfully withstood the two slurry applications and demonstrated thermal recovery after the second slurry application.

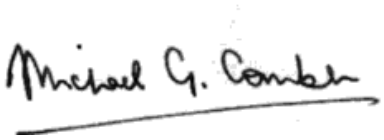
CONCLUSION: The PVI 144 kV rated arrester successfully passed the contamination test as specified in Section 8.7 of IEEE C62.11-1999 Standard.

TYPE TEST REPORT No. EU1250-HR-05

Seal Integrity Test

CERTIFICATION

This is to certify that the seal integrity design test has been successfully performed on Ohio Brass Type PVI Intermediate Class Surge arresters.



Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Seal Integrity Test

TEST OBJECTIVE: Seal integrity tests were performed per clause 8.8 of IEEE Standard C62.11-1999.

TEST SAMPLES: Tests were run on three 48 kV MCOV arresters.

TEST PROCEDURE: The seal integrity test consisted of the following steps:

a) Initial Electric Test: Resistive current and IIV were measured while each arrester was energized at MCOV.
b) Thermal Conditioning: Each arrester was placed in a 70°C ± 3° C environment for 14 days, after which the arresters were stabilized at ambient room temperature and watts was measured.
c) Seal Pumping: The arresters were heated to 60°C ± 3°C for one hour, then placed into a 4°C ± 3°C water bath for two hours, after which the samples were returned to the 60°C oven. Each arrester was subjected to ten repetitions of this cycle. The transfer time between media was 1-2 minutes.
d) Final Electrical Test: Step (a) was repeated.
e) Final Inspection: The arresters were disassembled to verify no moisture penetration was evident.

TEST RESULTS: The following table summarizes results of the seal integrity test.

Arrester No.	Applied Volts-kVrms	Initial Resistive Current-mac	Final Resistive Current-mac	Initial IIV microvolts	Final IIV microvolts
1	48	.13	.14	.6	.8
2	48	.13	.13	.8	1.0
3	48	.13	.14	.6	.8

CONCLUSION: Disassembly of the arresters showed no evidence of moisture penetration inside the arrester. Resistive current changed less than 50% and internal ionization measured less than 10 microvolts. The above testing confirmed that the PVI arrester design meets the seal integrity requirements as specified in Section 8.8 of IEEE C62.11-1999 Std.

TYPE TEST REPORT No. EU1250-HR-06

INTERNAL IONIZATION and RIV

CERTIFICATION

This is to certify that the internal ionization and RIV design tests have been successfully performed on Ohio Brass Type PVI Intermediate Class surge arrester.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Internal-ionization voltage (IIV) and RIV tests:

TEST PROCEDURE AND SAMPLE: Internal ionization and RIV testing was performed per clause 8.9 of IEEE Standard C62.11-1999. The test was performed on a 144 kV rated, 115 kV MCOV PVI arrester.

TEST EQUIPMENT: Equipment and test methods conformed to NEMA LA 1-1992 requirements. Prior to the test, the Stoddart Noise Meter NM-25T was calibrated using a General Radio Signal Generator Type 1001-A.

TEST RESULTS: A background noise level of μV was measured at an open circuit voltage of 100 kV. With the unshielded 144 kV rated arrester placed in the circuit, a noise level of 0.8 μV was measured at 121 kV (1.05 times MCOV) and 144 kV (rated) test voltages.

CONCLUSION: The 144kV rated PVI arrester passed test requirements per Section 8.9 of IEEE C62.11-1999 Standard, as measured noise levels were well within the 10 μV test limit.

TYPE TEST REPORT No. EU1250-HR-07

HIGH CURRENT, SHORT DURATION TEST

CERTIFICATION

This is to certify that the high current, short duration design test has been successfully performed on Ohio Brass Type PVI Intermediate Class surge arrester.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W.Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

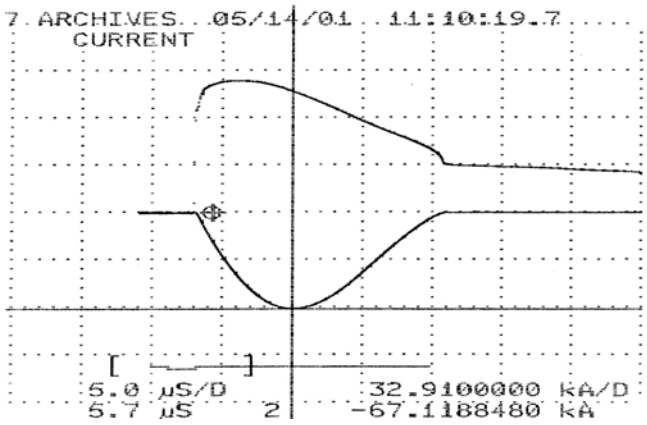
TITLE: High Current, Short Duration Discharge Withstand Test

TEST PROCEDURE: High current, short duration discharge withstand tests were performed per clause 8.10.1 of IEEE Standard C62.11.

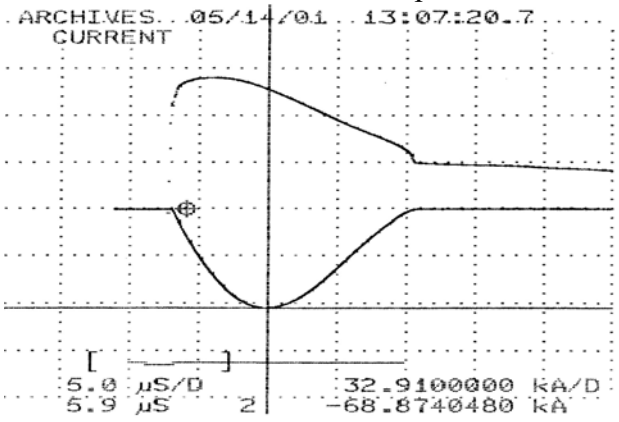
TEST SAMPLE: As required by clause 7.2.2, the prorated sample contains the minimum MOV mass allowed for the design. MCOV voltage was also prorated per unit Vref to reflect the lowest margin case of the standard voltage ratings offered in this design. Assigned MCOV of the prorated section was 9.10 kVrms.

TEST RESULTS: The test sample was subjected to two 65 kA, 4/10 discharges. Sufficient time was allowed between discharges for the sample to cool to ambient temperature 23 °C. Within 5 minutes after the second high current discharge, the sample was energized at the prorated recovery voltage. Watts loss was monitored over a 30 minute period demonstrating thermal stability.

First Shot
67.1 kA Magnitude
5.5/13.0 Waveshape

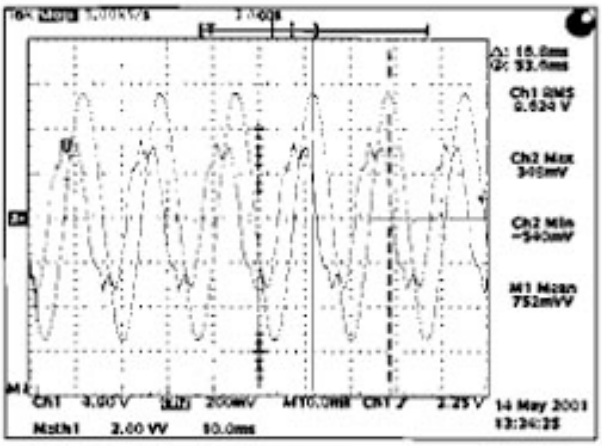


Second Shot
68.8 kA Magnitude
5.4/13.0 Waveshape



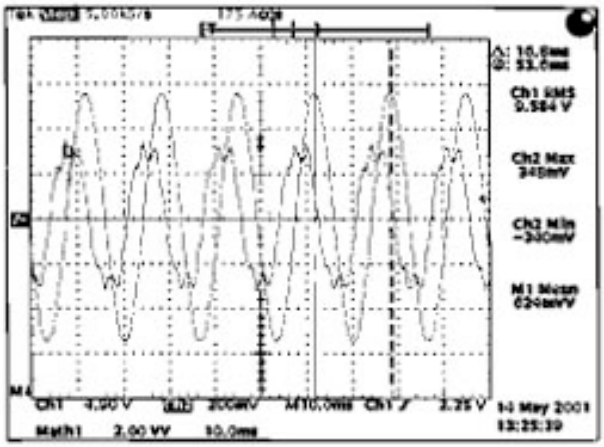
The following oscillograms monitor the arrester voltage and grading current during the 30 minute recovery test.

Osc 1



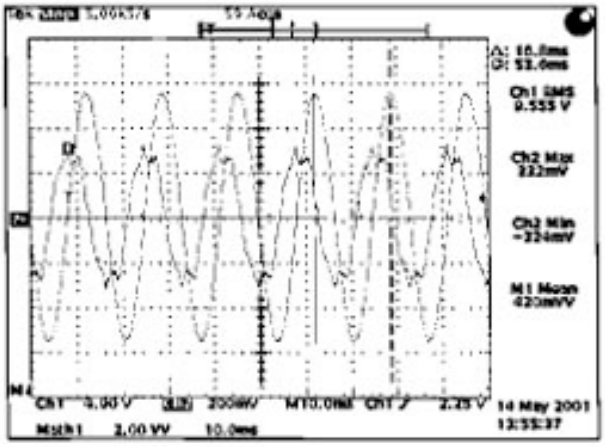
PVNA #8W Recovery @ Time 0 1kV/V 2.508mA/V

Osc 2



PVNA #8W Recovery @ 1 min 1kV/V 2.508mA/V

Osc 3



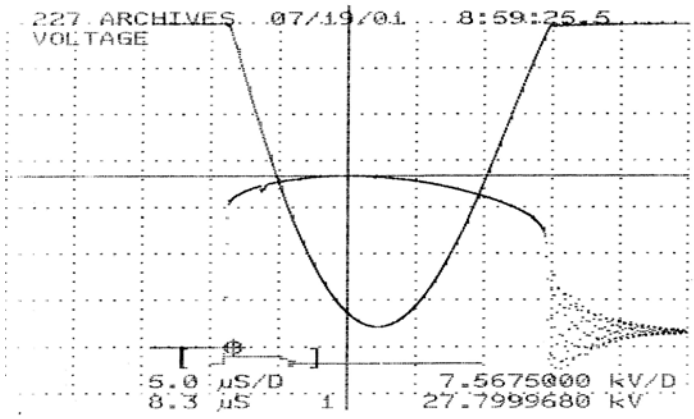
PVNA #8W Recovery @ 30 min 1kV/V 2.508mA/V

The following table summarizes the thermal recovery portion of the HCSD test.

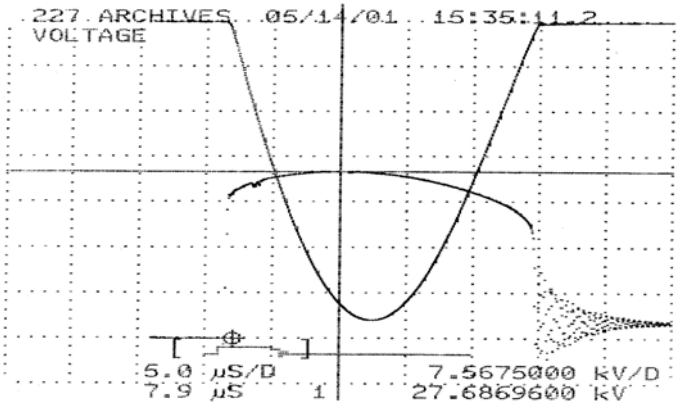
Time (minutes)	Recovery Volts (kVrms)	Section Watts	Section Current (mac)
0	9.62	1.89	1.35
1	9.58	1.57	.85
2	9.61	1.50	.85
5	9.58	1.34	.84
10	9.58	1.24	.84
20	9.61	1.16	.83
30	9.56	1.05	.83

Residual voltage at 10 kA was measured prior to and after the 100 kA discharge and thermal recovery tests. The following oscillograms verified the 10 kA discharge voltage remained unchanged within acceptable limits.

10 kA IR Before HCSD Test = 27.799 kV



10 kA IR After HCSD Test = 27.687 kV



CONCLUSION: The prorated test sample successfully completed the high current test and demonstrated thermal stability during the recovery test. The 10 kA residual voltage increased 1.0%, less than the allowed 10%. Disassembly revealed no evidence of physical damage to the test sample. The PVI design successfully met the High Current, Short Duration requirements of the Station Class Arrester.

TYPE TEST REPORT No. EU1250-HR-08

TRANSMISSION LINE DISCHARGE TEST

CERTIFICATION

This is to certify that the transmission line discharge design test has been successfully performed on Ohio Brass Type PVI Intermediate Class surge arrester.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Transmission Line Discharge Test: 161 kV System Application

OBJECTIVE: This test was performed per IEEE Standard C62.11 on a thermally prorated section of a full size arrester.

TEST SAMPLE: The test sample consisted of (2) 50mm diameter discs. The MCOV (9.44 kV rms) is assigned to represent the most severe condition; i.e., the minimum allowed discharge voltage level.

TEST PARAMETERS: The test setup is intended to model a 98kV MCOV arrester applied on a 161 kV system. The system parameters were derived from Table 11 of the C62.11 Standard. The system and prorated section parameters are defined as follows:

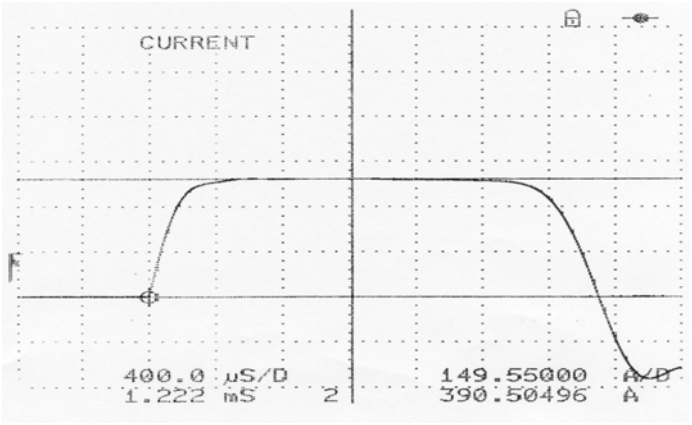
System Surge Impedance	400 Ohm
System Charge	359 kV
System Capacitance	2.44 Microfarad
Line Length	175 Miles
Equivalent Duration (TD)*	1890 Microseconds
Prorated Test Sample MCOV	9.44 kV RMS
Proratio Factor (K)	10.37
Required Generator Surge Impedance	38.53 Ohm
Required Generator Charge	34.58 kV
Required Generator Capacitance	25.53 Microfarad
Measured Generator Impedance (Zg)	36.75 Ohm
Measured Line Discharge Duration	2096 Microseconds
Equivalent Generator Line Length	194 Miles
Number of Generator Sections	10

*TD = miles times 10.8

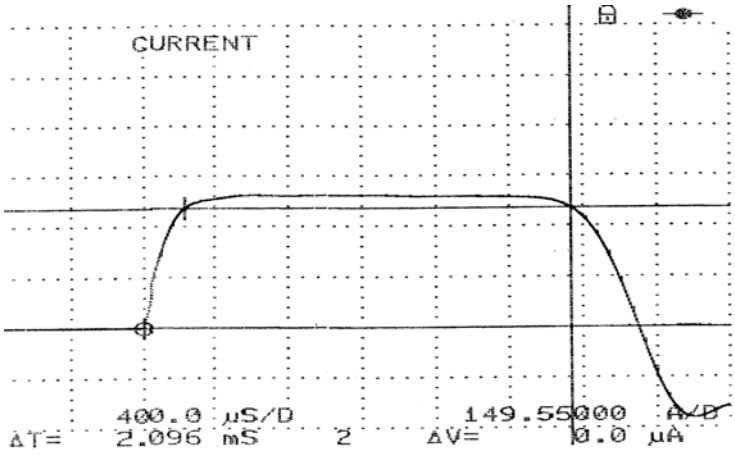
TEST PROCEDURE: Before and after the transmission line discharge test, the 10 kA 8/20 discharge voltage of the test sample was measured. The procedure was performed per Section 8.10.2.1.3 of the C62.11 Standard. The procedure consisted of subjecting the test specimen to three groups of six consecutive operations followed by one group of two operations with a time interval between consecutive operations of one minute. The test specimen was allowed to cool to ambient between Shots No. 6 and No. 7 and between Shots No. 12 and No. 13. After the eighteenth shot, the test sample was placed inside an oven and heated to 66^{o}C. After the heated test sample was subjected to Shots No. 19 and No. 20, the sample was energized at recovery voltage and thermal stability was demonstrated.

TEST RESULTS: The following figure measures the surge impedance and confirms the duration of the transmission line generator.

Zg = 14.35 Kv/390.5 Amps
Zg = 36.75 Ohms

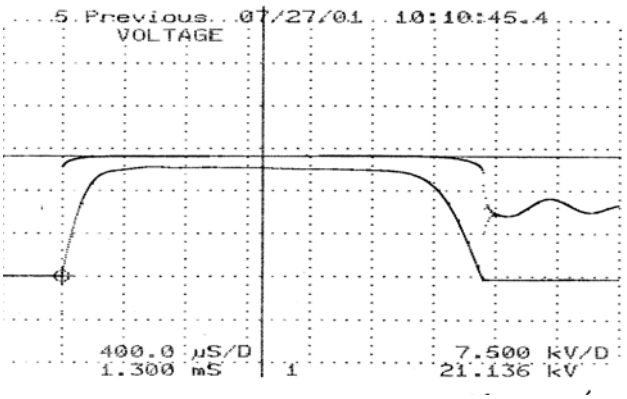


2096 Microsecond Duration = 194 Miles



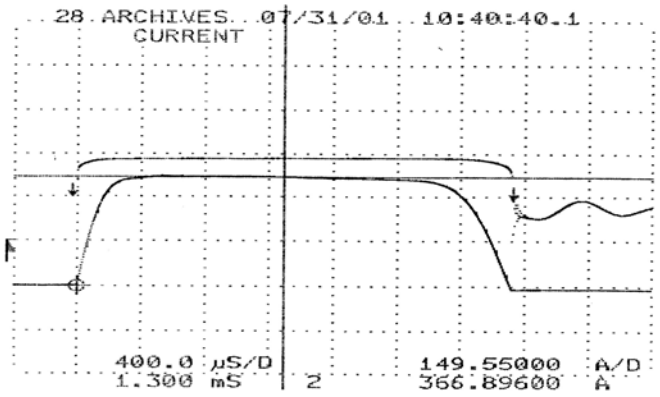
The following is an oscillographic record of the first transmission line discharge through the test sample.

Shot 1



After successful completion of the (18) shot test, the sample was preheated to 60oC. and subjected to two additional transmission line discharges spaced one minute. The following is an oscillographic record of the 20th shot.

Shot 20

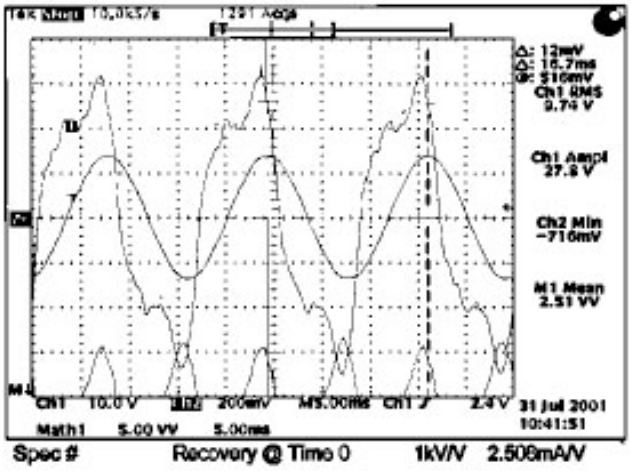


After the 20th shot, the sample was energized at recovery voltage (9.83 kV RMS). The sample remained energized until thermal stability was demonstrated. The following table summarizes the measured watts of the test sample during the recovery portion of the test.

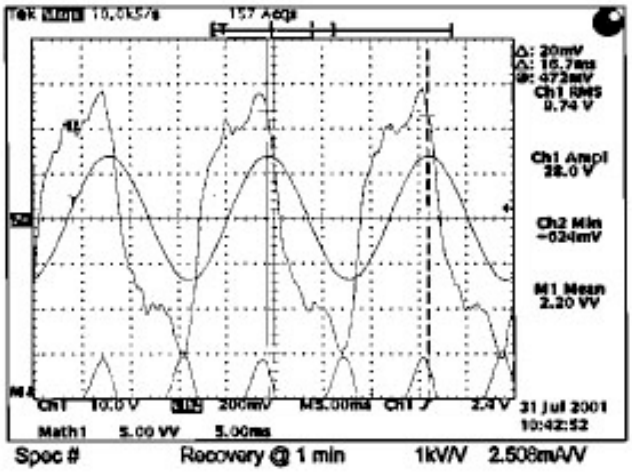
Applied Voltage (kV RMS)	Time (Minutes)	Sample Watts
9.83	0+	6.27
9.83	2	5.14
9.83	5	4.77
9.83	10	4.31
9.83	20	3.89
9.83	30	3.51

The following oscillograms show section grading current measured at time 0, 1 minute, and 30 minutes.

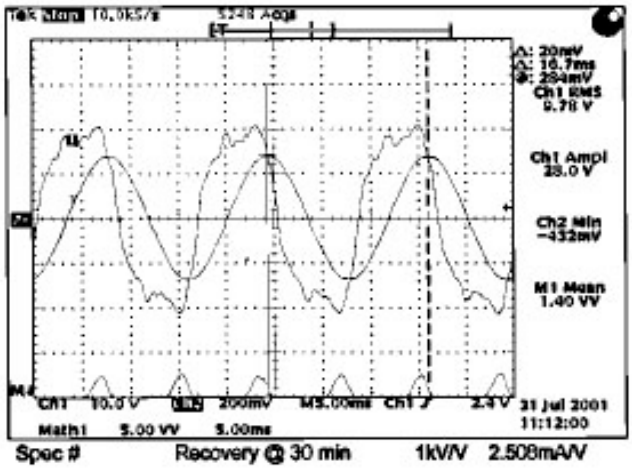
Osc 1



Osc 2

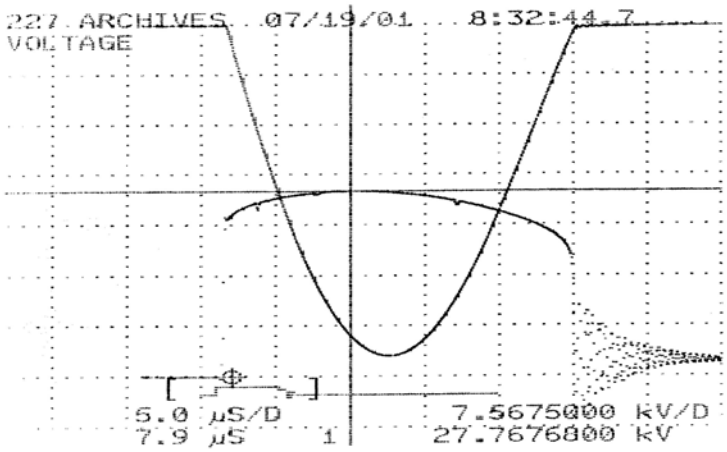


Osc 3

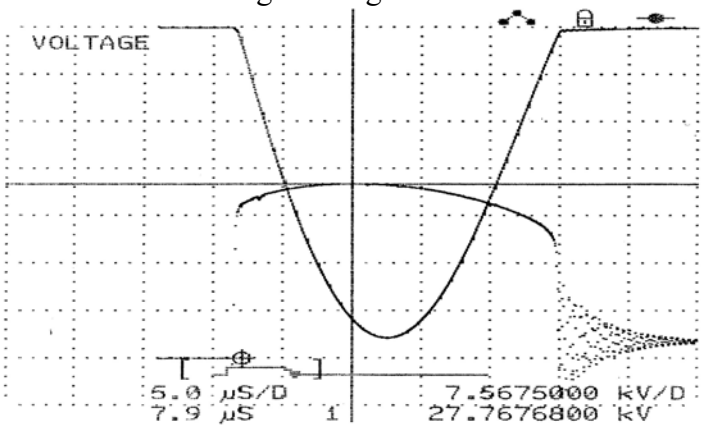


The sample 10 kA 8/20 discharge voltage was measured before and after the duty cycle test. The measured values are summarized below.

Before TLD Test
Discharge Current=10.00 kA
Discharge Voltage=27.77 kV



After TLD Test
Discharge Current=10.01 kA
Discharge Voltage=27.76 kV



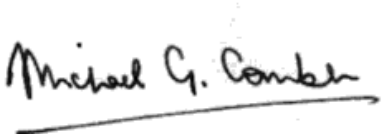
CONCLUSION: The prorated test sample successfully completed the transmission line discharge test per IEEE C62.11 standard and demonstrated thermal stability when energized at recovery voltage. The 10 kA 8/20 discharge voltage was unchanged, within the allowable 10% acceptance limit. Disassembly revealed no evidence of physical damage to the test sample. Therefore, the Type PVI test sample has successfully fulfilled the transmission line discharge requirements of an Intermediate Class Arrester applied on a 161 kV system.

TYPE TEST REPORT No. EU1250-HR-09

DUTY CYCLE TEST

CERTIFICATION

This is to certify that the duty cycle design test has been successfully performed on Ohio Brass Type PVI Intermediate Class surge arrester.



Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Duty Cycle Test:

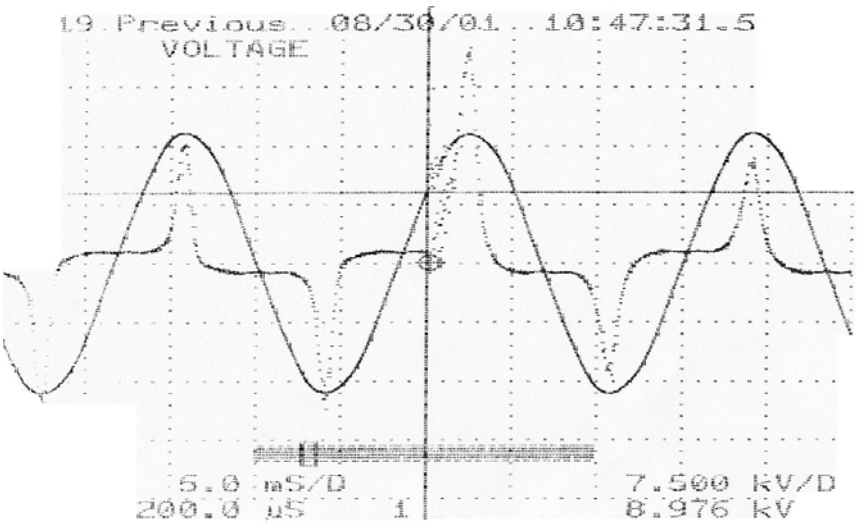
TEST OBJECTIVE: Section 8.11.1.3 specifies that the 20-shot rated voltage and 2-shot recovery portion of the Duty Cycle test on Intermediate Class arresters be performed with 5 kA 8/20 lightning impulses. Tests were actually performed with 10 kA surges.

TEST SAMPLE: As required by clause 7.2.2, prorated samples contained the minimum MOV mass per specified for the design. MCOV and rated voltages were also prorated per unit Vref to reflect the lowest margin case of the standard voltage ratings offered in this design.

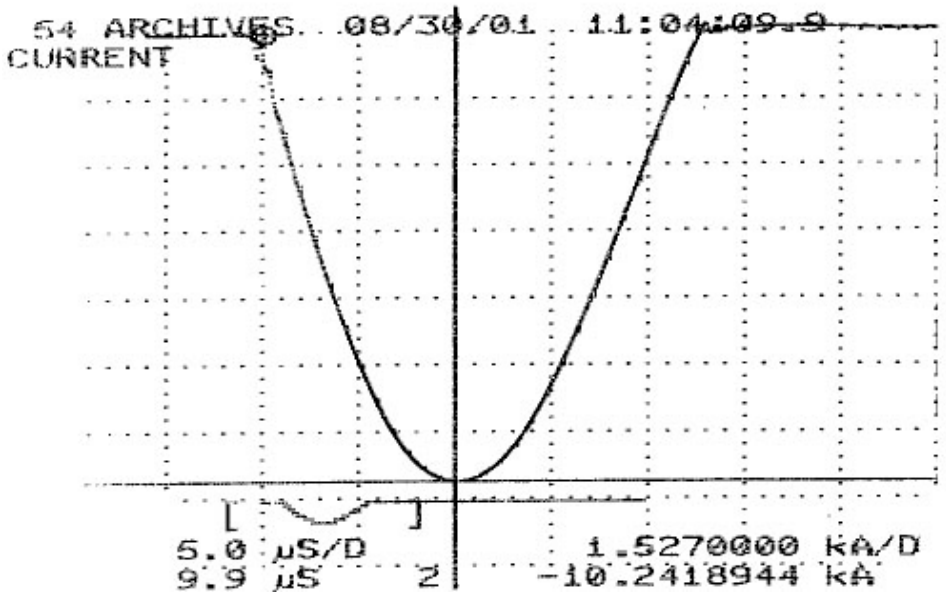
TEST PROCEDURE: The 9.42 kVrms MCOV test sample was energized at its 11.78 kV_{rms} rated voltage and subjected to twenty 10 kA, 8/20 discharges spaced at 1 minute increments. Following the twentieth impulse, the test section was placed in an oven at 60 °C. After reaching 60 °C, the sample was subjected to two 40 kA, 8/20 discharges. Within 5 minutes after the second high current discharge, the sample was energized at the prorated recovery voltage of 9.9 kV_{rms}. Watts loss was monitored over a 30 minute period demonstrating thermal stability.

TEST RESULTS: The following data summarizes the results of the duty cycle test.

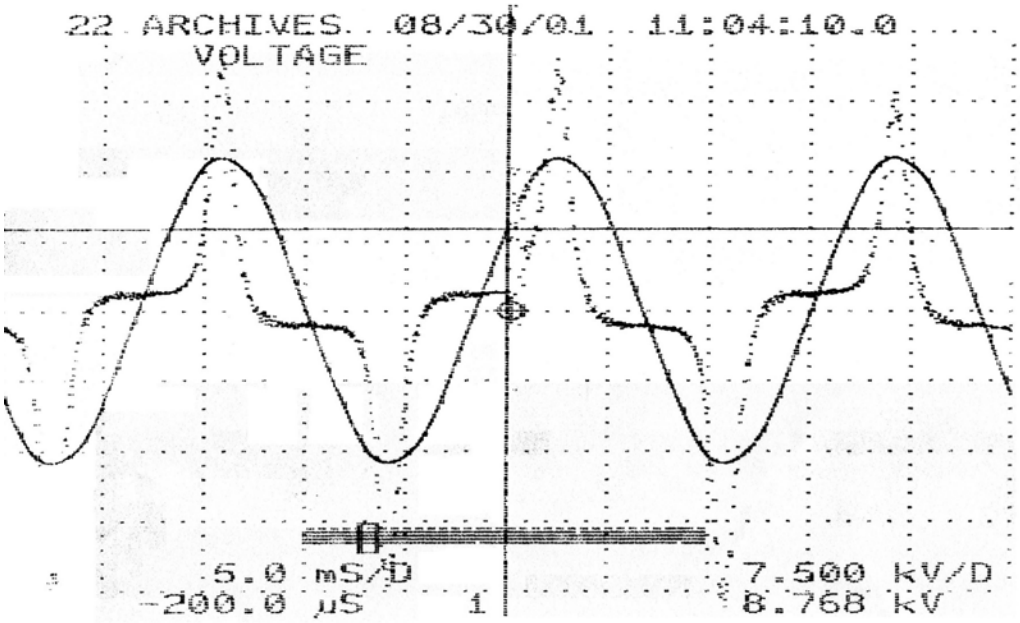
First Shot of 20 Shot Rated Voltage Duty Cycle Test



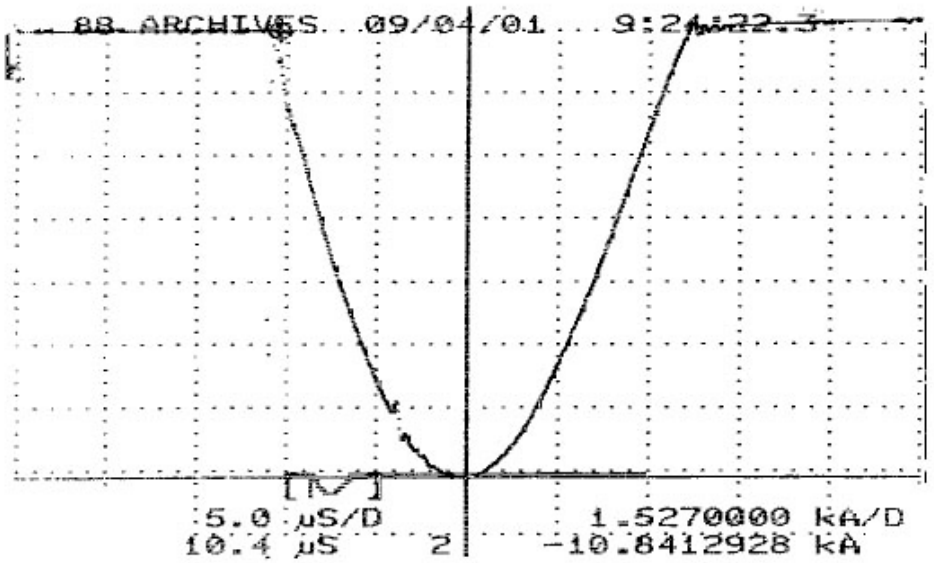
10 kA 8.1/18.8 Waveshape for 20 Shot Test



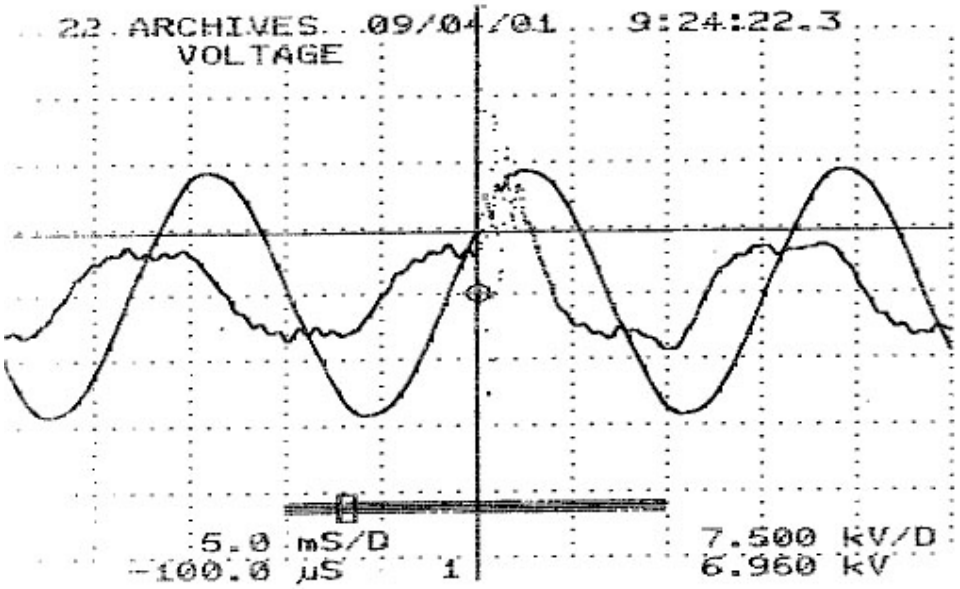
20th Shot of 20 Shot Rated Voltage Duty Cycle Test



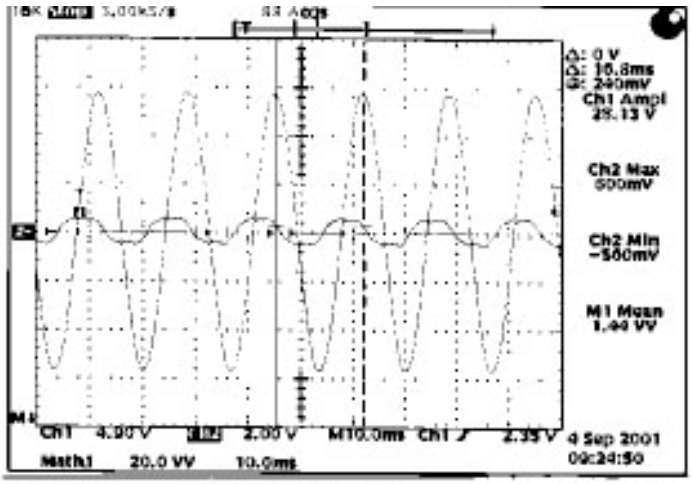
10.16kA 8.4/18.7 Waveshape for 2-Shot Test



Oscillogram of 22nd Shot

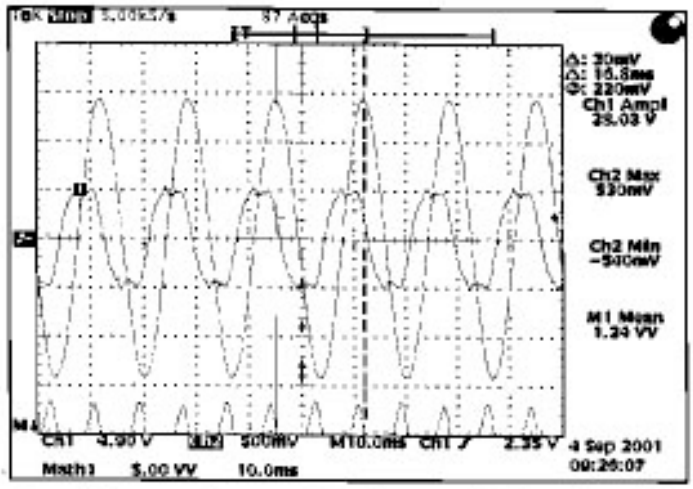


Immediately after the 22nd shot, the arrester section was energized at recovery voltage. The following oscillograms show section grading current measured at time 0, 1 minute, and 30 minutes.



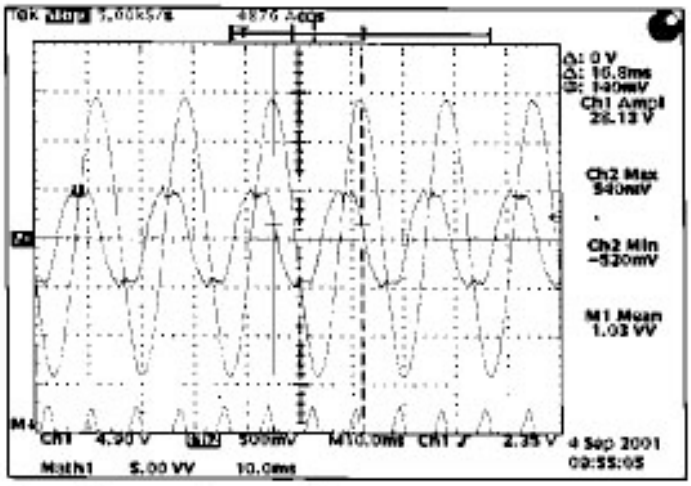
Spec #4 Recovery @ Time 0 1kV/V 2.508mA/V

Osc 2



Spec #4 Recovery @ 1 min 1kV/V 2.508mA/V

Osc 3



Spec #4 Recovery @ 30 min 1kV/V 2.508mA/V

The following table summarizes the results of the 20 shot rated duty cycle voltage test performed with 10 kA 8/20 initiating impulses.

Shot No.	Applied Voltage (kV_{rms})	Watts	Grading Current (ma_c)	8/20 Impulse (kA)
1	11.82	22.47	9.92	10.1
2	11.78	20.85	9.51	10.1
3	11.92	26.52	12.55	10.1
4	11.92	28.34	12.35	10.2
5	11.92	29.96	13.77	10.1
6	11.92	28.74	13.56	10.3
7	11.89	30.36	13.36	10.3
8	11.92	31.78	13.77	10.2
9	11.89	33.00	13.77	10.3
10	11.89	34.82	14.57	10.3
11	11.89	37.04	14.78	10.2
12	11.85	39.47	16.19	10.2
13	11.85	42.31	16.80	10.2
14	11.89	45.75	18.02	10.2
15	11.85	49.39	18.22	10.2
16	11.78	52.23	19.03	10.0
17	11.78	57.09	20.65	10.1
18	11.78	63.56	22.27	10.3
19	11.82	72.47	24.70	10.3
20	11.78	77.73	26.72	10.3

The following table summarizes the 21st and 22nd shots after sample preheating to 60^{o}C.

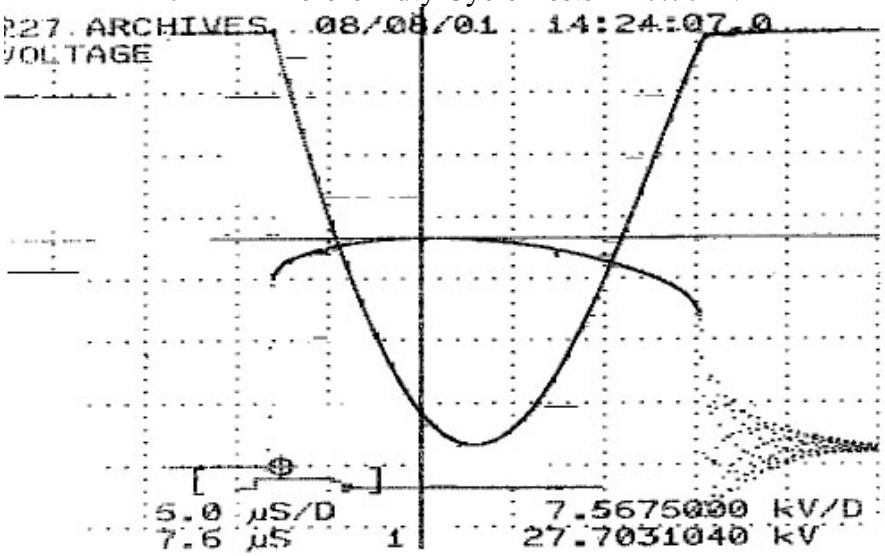
Shot No.	Applied Voltage (kV_{rms})	Watts	Grading Current (ma_c)	8/20 Impulse (kA)
21	9.91	2.78	1.40	10.3
22	9.91	3.09	1.43	10.2

The following table summarizes the recovery voltage portion of the duty cycle test.

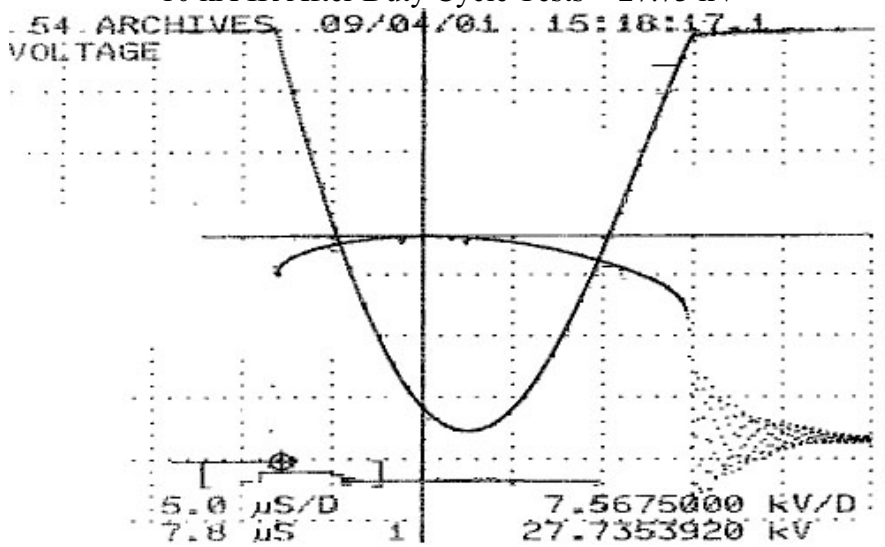
Time (minutes)	Applied Voltage (kV_{rms})	Watts	Grading Current (ma_c)
0	9.95	3.06	1.40
1	9.91	2.83	1.43
2	9.95	2.78	1.40
5	9.95	2.71	1.43
10	9.91	2.58	1.40
20	9.95	2.48	1.38
30	9.95	2.38	1.38

Residual voltage at 10 kA was measured prior to and following the Duty Cycle test series.

10 kA IR Before Duty Cycle Tests = 27.70 kV



10 kA IR After Duty Cycle Tests = 27.73 kV



Conclusion: The prorated test sample successfully completed Duty Cycle testing and demonstrated thermal stability during the recovery test. The 10 kA discharge voltage increased 0.1%, less than the acceptable 10% limit specified in Section 8.11.1.4 of C62.11-1999 Standard. Disassembly revealed no evidence of physical damage to the test sample. The PVI arrester successfully met the Duty Cycle requirements of the Intermediate Class arrester.

TYPE TEST REPORT No. EU1250-HR-10

TEMPORARY OVERVOLTAGE TEST

CERTIFICATION

This is to certify that the temporary overvoltage design test has been successfully performed on Ohio Brass Type PVI Intermediate Class surge arrester.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Temporary over-voltage tests (TOV):

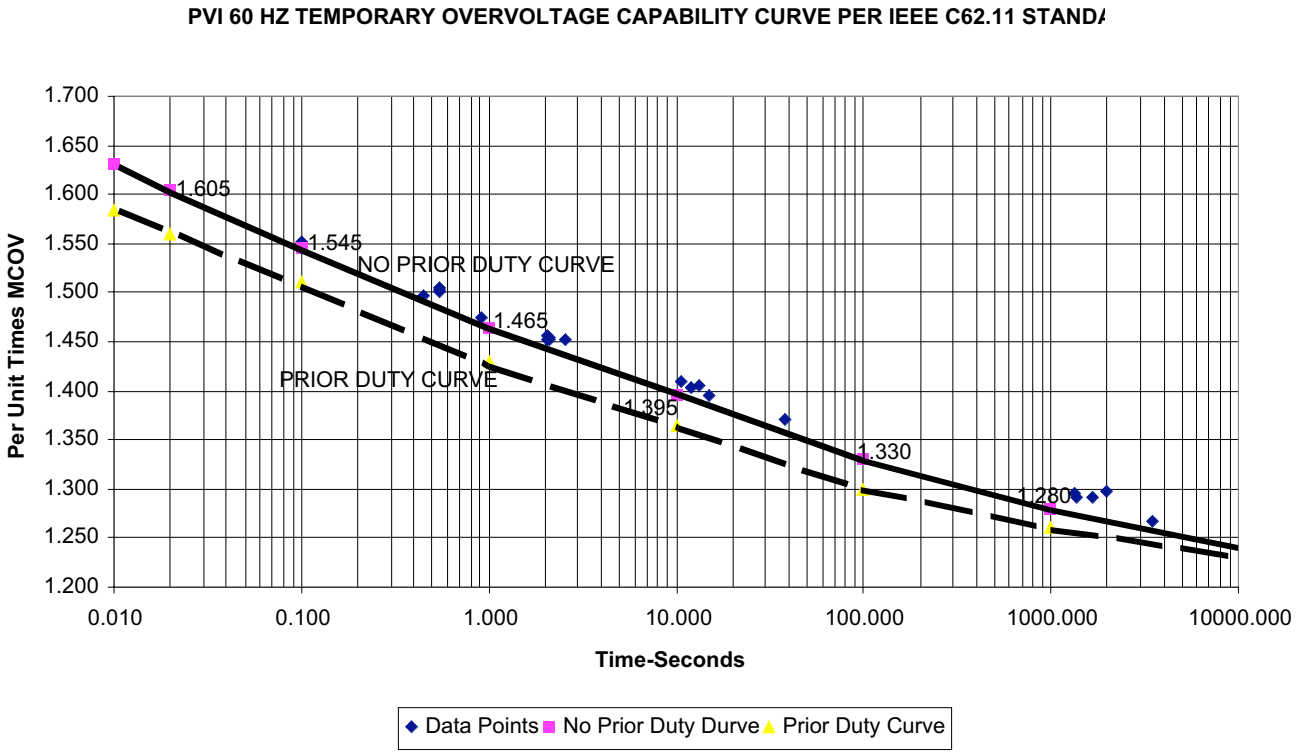
TEST SAMPLES: Temporary over-voltage tests were performed per clause 8.12 of IEEE Standard C62.11-1999. Tests were performed per Intermediate Class arrester requirements using five prorated test sections. Prorated sections were used to facilitate testing of the lowest MOV mass, highest stressed arrester rating at voltages within available laboratory facility capabilities.

TEST PROCEDURE: Per clause 8.12.1, each prorated sample was tested within five of the six designated time ranges a - f, spanning over-voltage durations of .01 - 10,000 seconds. Per clause 8.12.2, the tests were performed demonstrating TOV capability of the design under "no prior duty" conditions. For each TOV voltage setting, the test circuit applied voltage to the sample (preheated to 60^{o}C) for a time duration sufficient to exceed that claimed on the "no prior duty" curve. TOV voltage was superimposed over recovery voltage such that when TOV was removed, there was no delay prior to application of recovery voltage. Recovery voltage was applied for 30 minutes to demonstrate thermal stability.

TEST RESULTS: Tests were successfully completed on five PVI prorated samples in five specified time ranges. Each sample demonstrated thermal stability after TOV exposure having no signs of physical damage during inspection. Residual voltage at 10 kA measured prior to and following the complete TOV test series verified characteristics remained unchanged within acceptable limits. The following table summarizes the results of the TOV test program and applies to PVI arresters through 144 kV rating.

TOV DURATION (SECONDS)	NO PRIOR DUTY TOV (PER UNIT MCOV)	PRIOR DUTY TOV (PER UNIT MCOV)
.02	1.605	1.560
.1	1.545	1.510
1	1.465	1.430
10	1.395	1.365
100	1.330	1.300
1000	1.280	1.260

The following curve plots the individual “no prior duty” data points on the claimed TOV capability curve.


PVI 60 HZ TEMPORARY OVERVOLTAGE CAPABILITY CURVE PER IEEE C62.11 STANDA
Per Unit Times MCOV
1.700
1.650
1.600
1.550
1.500
1.450
1.400
1.350
1.300
1.250
1.200
1.605
1.545
NO PRIOR DUTY CURVE
1.465
PRIOR DUTY CURVE
1.395
1.330
1.280
0.010
0.100
1.000
10.000
100.000
1000.000
10000.000
Time-Seconds
Data Points
No Prior Duty Durve
Prior Duty Curve

TYPE TEST REPORT No. EU 1250-HR-11

PRESSURE RELIEF TEST

CERTIFICATION

This is to certify that the pressure relief design test has been successfully performed on Ohio Brass Type PVI Intermediate Class surge arrester.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Pressure Relief Test For Polymer Housed Intermediate Class Arrester:

TEST OBJECTIVE: Pressure relief tests were performed on the Type PVI polymer-housed Intermediate Class arrester per Section 8.13 of IEEE C62.11-1999 Standard.

TEST SAMPLES: Tests were performed on fusewire shorted arresters. Pressure relief tests were performed on the longest mechanical section, as required in Section 8.13.1 of the standard.

TEST PROCEDURE: A reduced voltage test source was used during the high current pressure relief test. Because of this , the claimable high current symmetrical current is the lesser of the Peak I/2.6, the Asymmetrical I/1.55, or the actual symmetrical current.

TEST RESULTS: The following table summarizes both the low and high current pressure relief tests. The high current pressure relief was performed on the longest 42 kV MCOV arrester section.

Sample MCOV	Mode of Failure	Test Volt kVc	Peak kAc	Asym kA rms	Symm kA rms	Calculate Symm. KA rms	Fault Durat Cycles	Description of Test Sample After Pres relief test
17	Puncture	16.8	--	.56	.56	.56	91	Module Intact Polymer Hsg in Position with 1" Vertical tear
17	Shorted	16.8	--	.57	.57	.57	91	Module Intact Polymer Hsg in position with 1" Vertical tear
42	Puncture	13.2	165	95.4	80.2	61.5	12	Module Intact Polymer Hsg Separated

CONCLUSION: Two tests arresters successfully passed the 600 amp low current requirement. The test arrester assembled with the longest mechanical unit met the test evaluation criteria as specified in Section 8.13.3 of IEEE C62.11-1999 Standard. In all tests, the arrester module remained intact after the completion of each test. The flexible polymer housing wall section split or separated, as intended, on all samples to allow venting of internal arcing gases to the outside of the arrester. In all cases, flames associated with the fault current test extinguished immediately after completion of the test, well within the allowed 2 minute duration. These tests have demonstrated the capability of the PVI arrester design to discharge a maximum claimable 61.5 kA_{rms} symmetrical fault current using the test procedure defined in Section 8.13 of IEEE C62.11-1999 Standard.

TYPE TEST REPORT No. EU1250-HR-12

MAXIMUM DESIGN CANTILEVER LOAD-STATIC TEST

CERTIFICATION

This is to certify that the maximum design cantilever load-static design test has been successfully performed on Ohio Brass Type PVI Intermediate Class surge arrester.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Maximum Design Cantilever Load-Static Test

TEST SAMPLES: The maximum design cantilever load (static) test was performed on a PVI 19.5 kV MCOV arrester. Tests were performed to validate the claimed 5000 inch-pound continuous cantilever rating.

TEST PROCEDURE: Testing was performed per the procedures specified in Section 8.19.2 of IEEE Std C62.11-1999. The test arrester was rigidly mounted at its base and top end loading applied to develop 5000 inch-pound cantilever load. With the arrester under load, the arrester was energized at 1,05 times MCOV and internal ionization was measured. Successive testing was performed at 0^o, 90^o, 180^o, and 270^o. Per paragraph d), the arrester was placed inside a thermal cycling oven for 96 hours and subjected to a combination of 5000 inch-pound load rotations and temperature excursions as specified in Figure 3 of C62.11-1999 Standard. After completion of the thermal cycling test, the IIV was remeasured in the four quadrants with the arrester energized at 1.05 times MCOV.

TEST RESULTS: The following table summarizes the results of the IIV tests with 1.3 and 2.0 microvolts of circuit background noise, respectively, for before and after testing.

IIV Testing Prior to and After Thermal Cycling

Arrester #	Direction of Applied 1200 in-lb Load (Degrees)	IIV @ 1.05 Times MCOV before Thermal Cycling (Microvolts)	IIV @ 1.05 Times MCOV after Thermal Cycling (Microvolts)
1	0	1.3	2.0
1	90	1.3	2.0
1	180	1.3	2.0
1	270	1.3	2.0

CONCLUSION: Per Section 8.19.3, the internal ionization levels measured with the arrester loaded to 5000 inch-pounds were unchanged as a result of the thermal cycling test. Visual examination revealed no evidence of mechanical damage. The above tests validated the electrical integrity of the PVI arrester assembled with a 3-lug base end casting when loaded to the 5000 inch-pound continuous cantilever rating

TYPE TEST REPORT No. EU 1250-HR-13

VERIFICATION OF THERMALLY PRORATED SECTION

CERTIFICATION

This is to certify that verification tests demonstrating thermal equivalency were successfully performed on Ohio Brass Type PVI Intermediate Class surge arrester.

Michael G. Comber
Manager – Engineering
Ohio Brass & Chardon Products

Dennis W. Lenk P.E.
Principal Engineer

10/27/03
Attachments

DESIGN TEST REPORT
PVI Intermediate Class Surge Arrester

TITLE: Verification of thermally prorated arrester section:

OBJECTIVE: Tests were performed per IEEE Standard C62.11 to validate the thermally prorated arrester section used on specified durability tests.

TEST SAMPLES: The longest PVI module was assembled with thermocouples located in the bottom quarter, center, and upper quarter locations. The average temperature of the three thermocouples was compared with the temperature of the thermally prorated section. In both cases, thermocouples were located between two adjacent MOV disks. The longest module was chosen to represent the highest percent MOV mass per unit arrester length.

TEST PROCEDURE: The full size arrester and prorated arrester section were heated to the target temperature using a 60 Hz source. The target temperature was 110 - 120 °C with test lab ambient at 20 +/- 3°C. The duration of applied voltage was 10 minutes. Within 1 minute after voltage was disconnected, the cooling rate of each test sample was monitored at 5 minute intervals.

CONCLUSION: Upon achieving the desired target temperature, the thermocouples were attached to a data logger and temperature was monitored continuously for 120 minutes. Figure 1 contains cooling curves verifying the longest PVI module arrester cooling rate was always greater than the prorated thermal test section.

Figure 1

Curves Verifying the Thermal Cooling Equivalency of the PVI Arrester to the Thermally Prorated Section