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Fuse Wire Arc Tester

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	mm	millimeter
A·h	ampere hour	mV	millivolt
°C	degree Celsius	min	minute
ga	gauge	rms	root mean square
h	hour	s	second
in	inch	V	volt
mA	milliampere	W	watt

FUSE WIRE ARC TESTER

By Peter G. Kovalchik[1]

ABSTRACT

To compare the viability of the new fuse wire arc test (FWAT) as a substitute for the comparative tracking index (CTI) for determining surface resistance to electrical tracking, the Bureau of Mines constructed a fuse wire arc tester and undertook a detailed testing program for testing insulating materials used on explosion-proof enclosures. This report describes the Bureau's apparatus, the two methods (CTI and FWAT), and the results of the Bureau's testing, showing comparisons of the FWAT with the CTI. Results showed strong correlation between the two methods, as all specimens tested that had CTI ratings of 400 V ac rms and above passed the 10-test sequence with the FWAT, whereas all specimens with lower CTI ratings failed, with the number of tests to failure corresponding roughly to the descending CTI rating order.

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INTRODUCTION

When certain insulating materials are decomposed by heat, highly explosive gases can be released. These insulating materials cannot be used within enclosures containing high-voltage circuits because they may be subjected to destructive electrical arcing. The commonly used method in the United States for determining if materials are highly resistant to electrical tracking is the CTI. Because the CTI is a difficult test to perform, an alternative method, the FWAT, was evaluated. The CTI method subjects low ac voltage (up to 600 V ac rms) at low current to the surface of an electrical insulating material (fig. 1). This is accomplished by applying the voltage between two electrodes (fig. 2) in contact with the surface of the insulating material. The current results from an aqueous contaminant (electrolyte), which is dropped between the electrodes every 30 s. Voltage is maintained across these electrodes until the current flow reaches 1 A. This value of current constitutes failure. Additional test specimens of the same material are tested at different voltages until failure. The results of these tests are graphically represented by plotting the number of drops required to cause failure versus the applied voltage. From this graph, the CTI value of particular insulating material can be determined. The CTI is defined as the value of the rms voltage that will allow 1 A to flow when the number of drops of contaminant required is equal to 50. This value provides an indication of the track resistance of the material.

ASTM SYMBOL KEY

A_1 Ammeter	S_1 Shorting switch
J_1 Testing fixture	T_1, T_2 Variable power source
R_0 Over-current relay	V_1 Volt meter
R_1 Current-limiting resistor	

FIGURE 1.—Comparative tracking index electrical circuit.

FIGURE 2.—Comparative tracking index electrodes arrangement.

FIGURE 3.—Fuse wire arc test electrodes arrangement.

The alternative FWAT method subjects the surface of an electrical insulating material to 500 V ac peak (354 V ac rms) and 100 A dc. This is accomplished by applying the alternating-current voltage and high direct current across two electrodes, located as shown in figure 3.

A copper wire is sandwiched between two pieces of the test specimen with the ends of the copper wire connected to the two electrodes. When power is applied to the electrodes, the copper wire fuses from the high direct current, resulting in a carbon track. Immediately after fusing occurs, 500 V ac peak is maintained across the ends of the copper wire. This voltage then subjects the surface of the test specimen to electrical stress. If sufficient carbonization has taken place, alternating current will flow. The value of this alternating current is the criterion of the test. If 1 A ac or more flows, the insulating material fails the test. If less than 1 A ac flows, the test is repeated until either 1 A ac or more flows, or until 10 tests have been conducted. This method determines if the insulating material is highly resistant to electrical tracking by a pass or fail result.

The CTI, ASTM Standard D 3638 077, has several disadvantages. It is completely impractical for the majority of users because the apparatus is not mobile and requires electrolyte solutions. The electrolyte, an ammonium chloride (NH_4Cl) solution, must be prepared accurately to ensure that conductivity of the solution remains constant. Also, the instrument should not become contaminated with the NH_4Cl solution.

The FWAT, Electrical Research Association Report 5078:1964, is completely practical for the majority of users. It uses no electrolyte solution and requires only 240 V ac rms. The tests are short, simple, and are repeated on the same pair of specimens at intervals of 1 to 2 min.

MECHANICAL APPARATUS

A photograph of the apparatus is shown in figure 4, and a detailed mechanical drawing is shown in figure 5. The main design feature is the heavy terminal construction. These brass terminals provide an excellent electrical connection and minimize local heating. Also, there is a provision for vertical movement, which enables the fuse-wire connection to be made at the test specimen. This will enable tests on specimens up to 1-1/2 in thick.

The clamping arrangement is a simple design. It is only required to prevent movement of the specimen. The front and top of the clamping arrangement are hinged to facilitate easy access to the test specimen. A 20-ga spring steel wire is placed parallel to and 3/4 in away from the fuse wire. To prevent the fuse wire from moving when the high current is applied, the clamping screw applies pressure through the 1/2-in asbestos-free sterling board midway between the fuse wire and steadying wire.

FIGURE 4.—Fuse wire arc test mechanical apparatus.

FIGURE 5.—Drawing of mechanical apparatus.

ELECTRICAL CIRCUIT

The electrical circuit (fig. 6) consists of commercially available parts, except for a specialty transformer (T2) that is shown in figure 7. These parts consist of:

(B1)	battery: 12-V lead acid
(BC1)	battery charger: 12 V, 50 A•h
(CR1, CR2)	time-delay relays: 0-120 s, 12 V dc - coil
(CR3)	dc contactor: 220 to 250 V dc, 135 A, 2 poles
(CR4)	battery relay: 12 V dc - coil
(F1)	20-ga wire
(IA1)	isolation amplifier: gain = 100 isolation = 1,500 V dc
(L1)	220-V lamp
(L2)	12-V lamp
(M1)	voltmeter: 0-500 V ac rms
(M2)	battery-charger meter: 0-10 A
(M3)	ammeter: 0-200 mA ac
(PS1, PS2)	power supplies: 12 V dc, 1 A 220 V dc
(R1)	current-limiting resistor: 20 to 25 ohms 3,000 to 4,000 W
(R2)	shunt: 100 A, 200 mV
(S1, S2, S3)	power switches: 240 V ac, 30 A
(S4)	micro switch: 1 pole
(T1)	variable transformer: input 240 V ac rms output 0 to 280 V ac rms
(T2)	specialty transformer
(T3)	filament transformer: 1 to 18.5 ratio
(T4)	step-down transformer: 2 to 1 ratio

FIGURE 6.—Fuse wire arc test electrical circuit. (See section "Electrical Circuit" for explanation of symbols.)

FIGURE 7.—Mechanical drawing of specialty transformer (T2).

The essential requirements of the electrical circuit and its components are that it should be capable of causing a current of approximately 100 A dc to flow in 20-ga copper wire and also produce a voltage of 500 V ac peak across the ends of the wire immediately after fusing occurs.

A lead acid battery of 50 A•h will supply sufficient current to fuse the wire. The follow-up alternating current voltage is obtained with a specialty transformer (fig. 7) designed with a 250-V ac rms primary and a heavy-duty secondary winding, which provides a voltage of 500 V ac rms. A current limiting resistor (20 to 25 ohms), along with the variable transformer, will reduce the secondary of the specialty transformer to 500 V ac peak. It is critical for the secondary circuit to have a direct-current resistance less than 0.1 ohm to ensure the battery will be capable of delivering sufficient current.

The remaining components of the electrical circuit are explained in detail in the system-control section.

SYSTEM CONTROL

The fuse wire arc tester must be powered by 240 V ac rms through the standard 240 V ac plug provided. Before energizing the unit, make sure all switches are in the off or neutral position, the voltage control is at zero, and the safety shield is down. This is to prevent any possible electrical shock. After completing these steps, the control sequence can begin.

Place the test specimens in the mechanical apparatus with the 20-ga copper wire in position. Then raise the safety shield up to activate micro switch S4. This will supply power to relay CR2, which allows power to the brass terminals if all other switches are in the correct position. Switch S1 is then closed and power is applied to all power supplies. Then switch S2 is closed to activate relay CR4, which then activates the battery-charging circuit. Meter M2 will indicate if the battery is sufficiently charged. If it is not, time must be taken to allow sufficient charging. Once the battery is charged, switch S2 is closed to apply power to the specialty transformer (T2).

FIGURE 8.—Voltage setting of variable transformer (T1) for fuse wire arc tester.

The variable transformer (T1) is adjusted so the voltmeter (M1) reads 354 V ac rms (500 V ac peak, figure 8). When the specimens and fuse wire are in position and the correct voltage is present, a test can be conducted. Switch S3 is closed, which enables a time-delay relay CR1. The time-delay relay can be set anywhere from 0 to 120 s, allowing the operator to move a few feet away from the apparatus and still be able to watch the meters and avoid flying sparks. The contacts of relay CR1 close and activate the direct-current contactor (CR3). The direct-current contactor (CR3) closes, allowing 100 A dc to flow through the fuse wire and saturate the transformer (T2) core. At the same time, 240 V ac rms are applied at the primary of the specialty transformer (T2), causing current to flow. This current is limited to 10 A ac because of the 20- to 25-ohms current-limiting resistor (R1). The copper wire fuses and the direct-current field in the transformer (T2's) core collapes. As a result, energy is dissipated in an arc on the surface of the test specimen. At the same time the primary reactance increases, transformer (T2) assumes its normal operation with voltage across the ends of the fuse wire rising to 500 V ac peak. This 500 V ac peak stresses the surface of the specimen. If sufficient carbonization has taken place, meter M3 will read this current and, if it exceeds 1 A, the specimen fails and the test is concluded. If the current is less than 1 A, another test must be conducted on the same specimen. The testing is repeated at 1-1/2-min intervals until either conduction of 1 A or more occurs, or 10 wires have been fused.

EXPERIMENTAL METHOD

Objective. - To determine the resistance to arc conduction of insulating materials. The materials tested are listed in table 1.

Test Specification: Test specimens consisted of two pieces, 6 by 2 in. All pieces were flat and free from surface defects.

Conditioning: All specimens were conditioned in an environmental chamber, Tenny model BTH202000, as stated below:

1. Temperature, 20° + 2° C.
2. Humidity, 65%±5%.
3. Time, 18 to 24 h.
4. Time to test after removal, 3 min.
5. Test method for FWAT procedure:
   - A. All switches in off or neutral position and safety shield down.
   - B. Plug fuse wire arc tester into 240 V ac line.
   - C. Place test specimen in mechanical apparatus with fuse wire in position.
   - D. Place safety shield up.
   - E. Turn main-power switch on.
   - F. Turn battery-charger switch on and check ammeter to see if battery needs charging.
   - G. Turn same switch, but in opposite direction, for ac voltage.
   - H. Adjust voltage control for 354 V ac rms, as shown in figure 8.
   - I. Turn test switch on and step back several feet.
   - J. Read and record alternating current.
   - K. If alternating current of 1 A or more flows, the material fails.

If alternating current is less than 1 A, repeat the procedure on the same specimen until 1 A flows or 10 tests are completed.

TABLE 1. - Materials tested and test results of fuse wire arc testing program

Material			CTI value, V	FWAT tests to failure[1]
Tradename	Type	Description		
RF1002.....	Nylon 6/6.....	Glass flame retardant.	>600	Passed
RF1008.....	Nylon.....	NA.....	>600	Passed
64A.....	Nylon 6/6.....	NA.....	>600	Passed
PF1006.....	Nylon 6.....	Glass reinforced.....	525	Passed
8202.....	...do.....	NA.....	475	Passed
8231.....	...do.....	14% glass fiber.....	475	Passed
R200.....	Nylon 6/6.....	NA.....	435	Passed
M340.....	...do.....	Flame retardant.....	290	10
909.....	...do.....	Glass reinforced, flame retardant.	255	4
DR48.....	Polyester.....	Flame retardant 30% glass fiber.	235	3
RTP204FR.....	Nylon.....	Glass reinforced.....	200	3
420.....	Polyester.....	Flame retardant 30 glass reinforced.	185	1
RTP303.....	Polycarbonate.....	NA.....	150	1

NA Not available.

[1]10 total tests; those that "passed" did not fail within this testing series, but actual number of tests to failure was not determined for those that passed the 10 tests.

RESULTS AND CONCLUSIONS

Test results showed that the FWAT results are comparable with those of the CTI. Specimens tested had CTI ratings of 400 V ac rms and above and 290 V ac rms and below; those having ratings of 400 V ac rms and above passed while those with 290 V ac rms and below failed. It appears from these results that as the CTI values increased from 150 to 290, the number of tests required to make the specimen break down or fail also increased. This is understandable, because as more FWAT tests are conducted, more carbonization forms on the test-specimen surface. When sufficient carbonization has taken place, more current will flow and eventually break down will occur. By examining CTI values, we know that as this value increases, the surface resistance to arcing increases.

In summary, higher surface-resistance values need more carbonization for current to flow; as the CTI value increases, the number of FWAT tests increase. Since the FWAT uses 354 V ac rms to electrically stress the surface of the specimen, it can be expected that CTI values greater than or equal to this voltage will pass as proven by the test results.

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