



ATF Fire Research Laboratory Technical Bulletin

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Arc Melting on Cables Protected by Arc Fault Circuit Interrupting, Ground Fault Circuit Interrupting, and Thermal Magnetic Circuit Breakers

Abstract

The purpose of this Technical Bulletin is to provide the photographs and waveforms produced during the testing and research that examined the relationship between the formation of arc melting and the type of circuit protection device used on the circuit. Electrical cables commonly used in residential wiring in the United States were subjected to various radiant heat fluxes from a radiant cone heater. Each test cable section was protected by one of three types of circuit breakers: thermal-magnetic, arc fault circuit interrupting, and ground fault circuit interrupting. The relationship between the presence or absence of arcing damage (arc melting) and the type of circuit breaker was explored.



As discussed in “A Comparison of Heat Impinged Conductors,” the formation of arc melting on electrical wiring can be influenced by the type of circuit protection device used to protect a branch circuit [1]. Knowing the type of circuit protection device can affect the formation of arc melting on electrical wiring is important for those involved with the investigation of fires because it may be possible to find a tripped circuit breaker with no corresponding area of damage on the branch circuit conductors. This has great implications for the process of the examination of the electrical system, as it will influence the results of the investigator’s arc map.

This project exposed nonmetallic sheathed (Type NM) cables to heat fluxes of 35 kW/m², 45 kW/m², and 55 kW/m² from a radiant cone heater. Thermal-magnetic (TM), arc fault circuit interrupting (AFCI), and ground fault circuit interrupting (GFCI) circuit breakers were used to protect the cable samples. The Type NM cables and circuit breakers were of the type commonly used in electrical systems in the United States, particularly residential electrical systems. The cables were 14/2 AWG with ground and the circuit breakers were rated for 15 A. The cables were exposed to the radiant heat fluxes until the circuit breaker activated, shutting off power to the circuit. The voltage and current waveforms were recorded with a power quality analyzer.

After testing, any resulting damage caused by an arcing event (referred to as arc melting) was examined and documented with a microscope and enhanced with high dynamic range (HDR) photography software. Attachment 1 contains the photographs and electrical waveforms from the testing. All arc melting artifacts observed were visually consistent with the characteristics of arc melting presented in the 2021 edition of NFPA 921: Guide for Fire and Explosion Investigations [2].



Recommendations

Fire investigators and forensic engineers should understand that there may be conditions which may prevent an electrical fault from creating arc melting on electrical wiring during a fire. Other publications and presentations recommend that the investigator start their examination of the electrical system on the exterior of the structure, working their way inside and downstream [3, 4]. The investigator may find it beneficial to identify tripped circuit breakers, tracing the circuits and following the tripped circuits downstream to identify what caused the circuit breakers to activate. This will help to ensure a thorough understanding of the electrical system and identify as much data as possible. It is important, however, to keep in mind that the conditions that could prevent arc melting from forming can be important in the examination of the electrical system and the creation of an arc map.

References

- [1] Franzi, K., Novak, C. & Keller, M.. (2021). A Comparison of Heat Impinged Conductors. Fire & Arson Investigator, 71 (4), 12-18.
- [2] National Fire Protection Association. (2021). NFPA 921: Guide for Fire and Explosion Investigations. Quincy, MA.
- [3] Novak, C. (2020). Methodology for the Examination of an Electrical System by Fire Investigators and Engineers. Fire & Arson Investigator, 70 (4), 30–37.
- [4] Electrical Aspects of Fire Scenes (2017), ATF Advanced Origin and Cause and Courtroom Techniques training materials.





Figure 1. Arc melting produced in Test 1 of an AFCI circuit breaker at 35 kW/m².

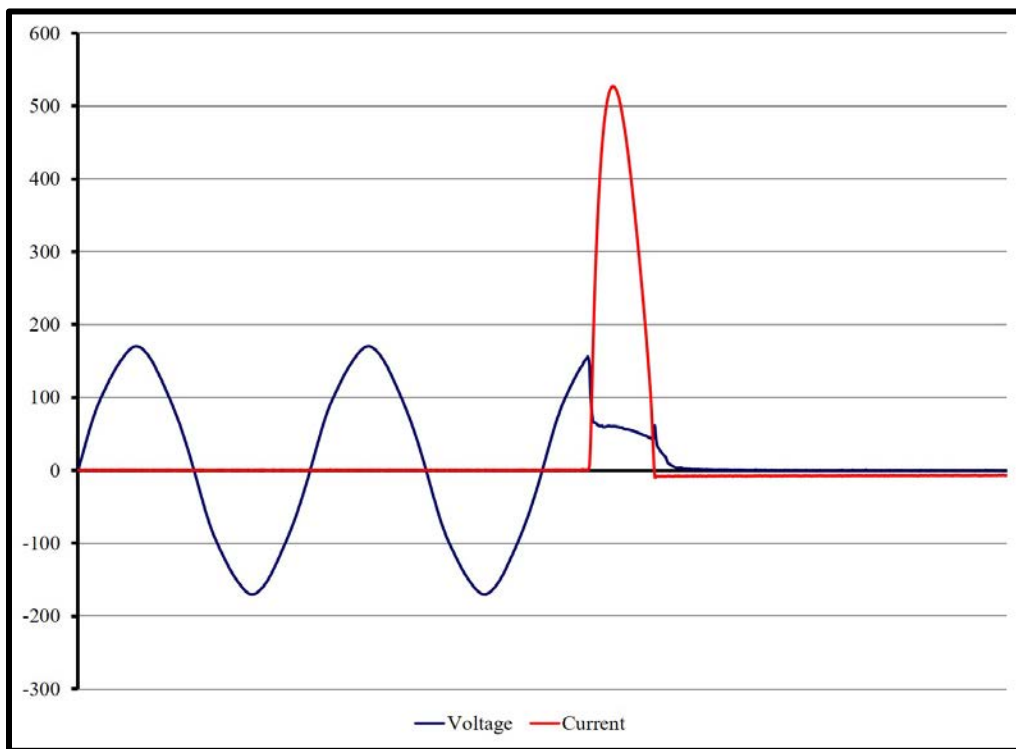


Figure 2. Waveforms of voltage (volts) and current (amperes) produced during Test 1 of an AFCI circuit breaker at 35 kW/m².

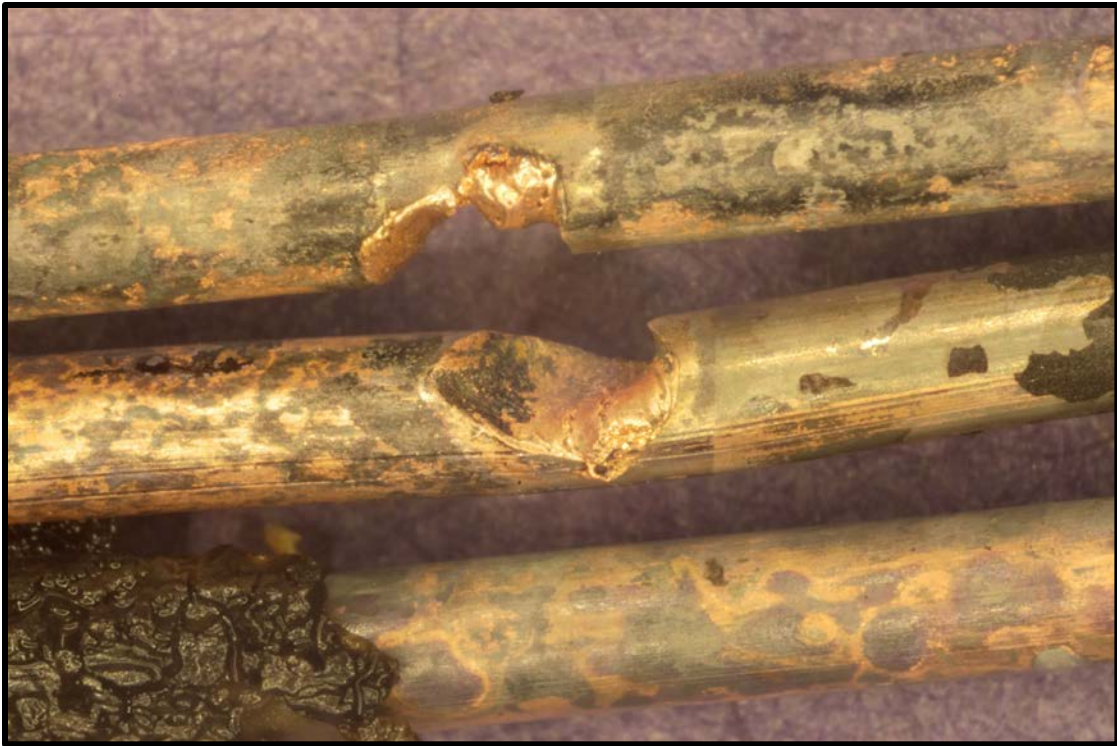


Figure 3. Arc melting produced during Test 2 of an AFCI circuit breaker at 35 kW/m².

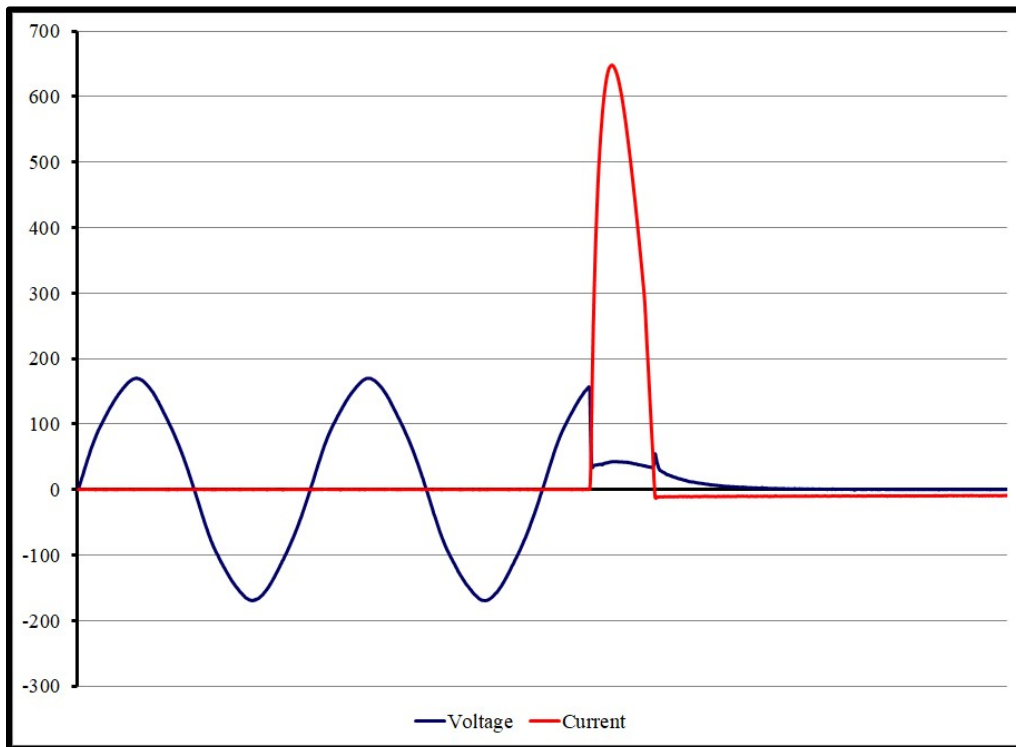


Figure 4. Waveforms of voltage (volts) and current (amperes) during Test 2 of an AFCI circuit breaker at 35 kW/m².

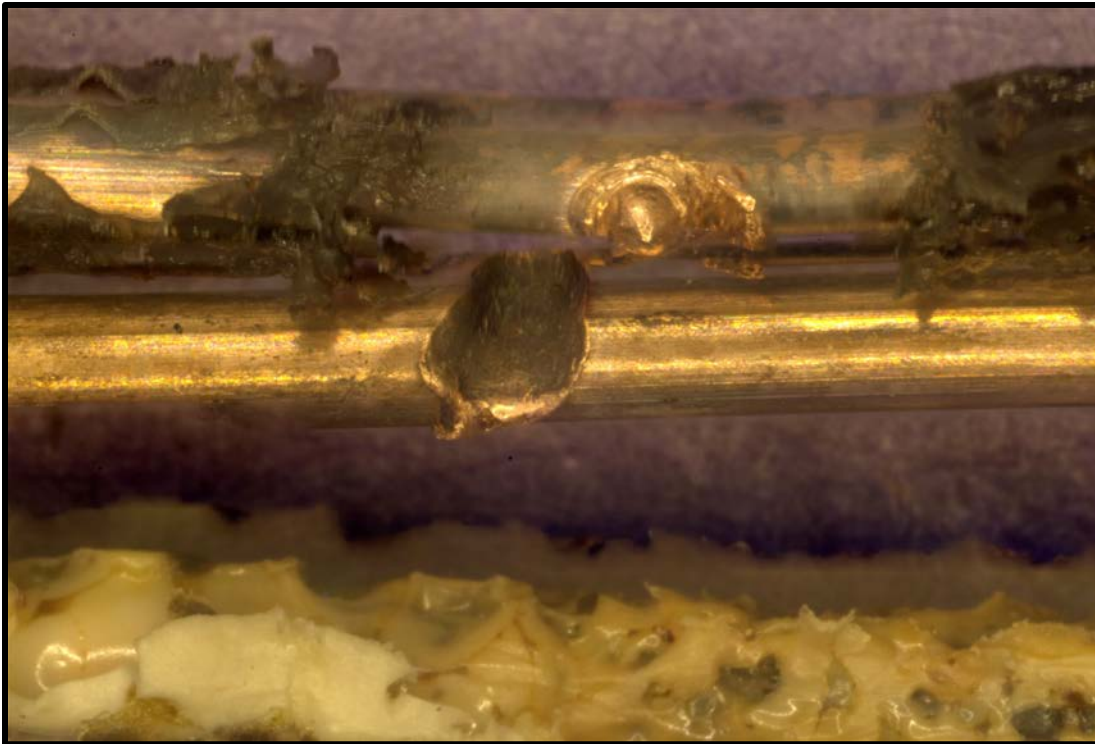


Figure 5. Arc melting produced during Test 3 of an AFCI circuit breaker at 35 kW/m².

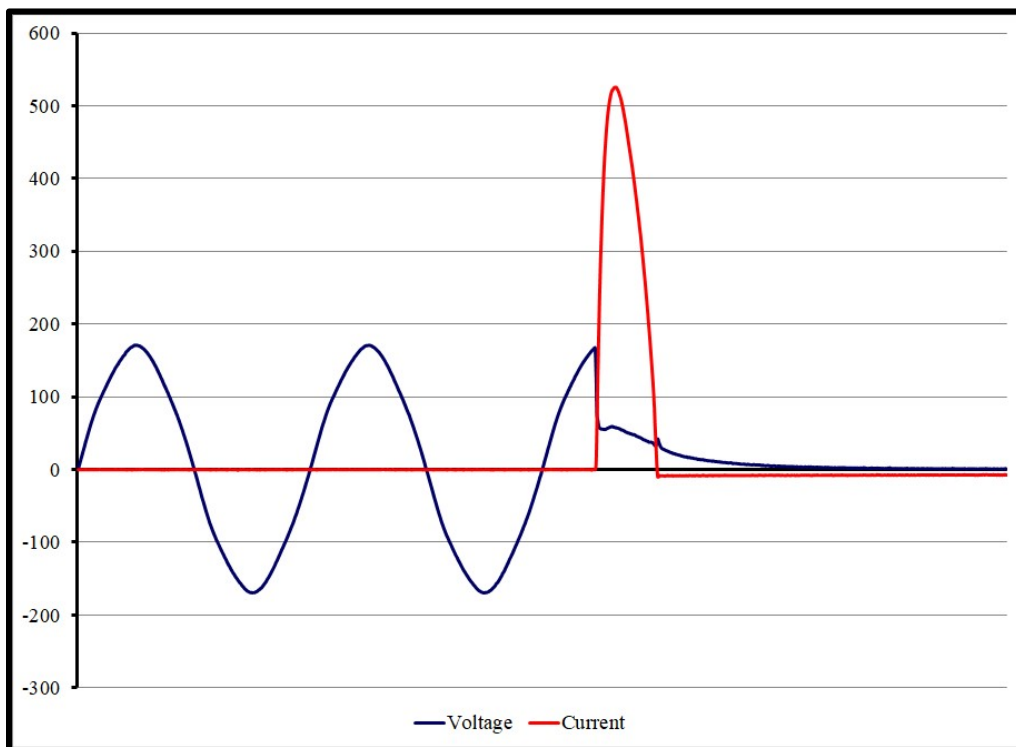


Figure 6. Waveforms of voltage (volts) and current (amperes) during Test 3 of an AFCI circuit breaker at 35 kW/m².



Figure 7. Absence of arc melting produced during Test 1 of an AFCI circuit breaker at 45 kW/m².

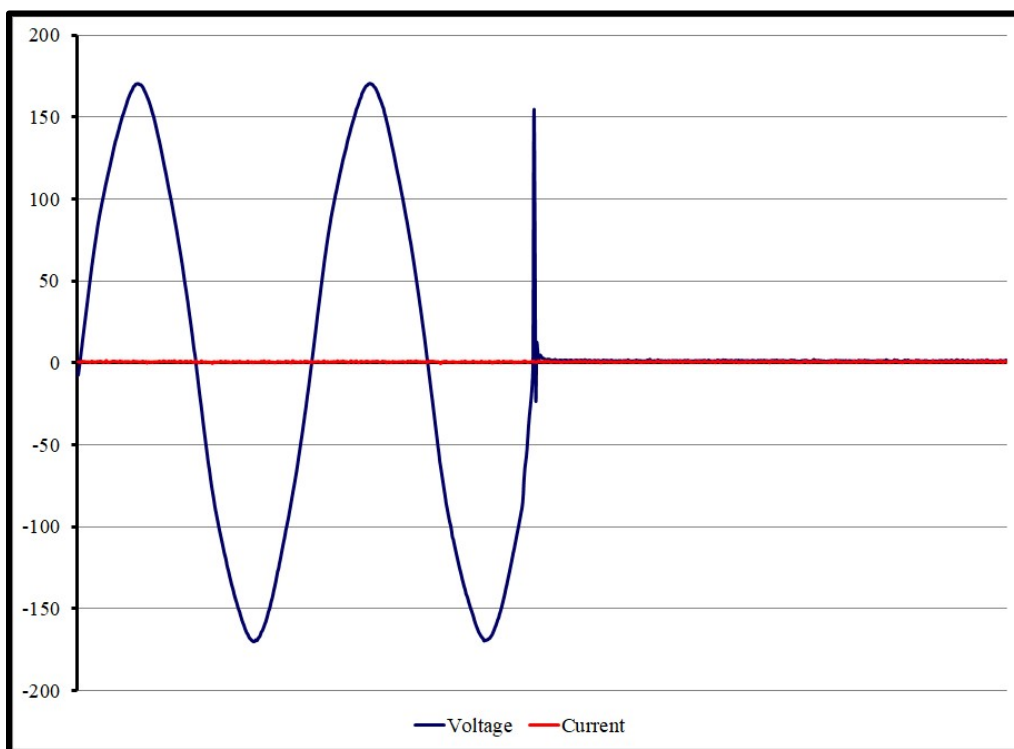


Figure 8. Waveforms of voltage (volts) and current (amperes) during Test 1 of an AFCI circuit breaker at 45 kW/m².



Figure 9. Absence of arc melting produced during Test 2 of an AFCI circuit breaker at 45 kW/m².

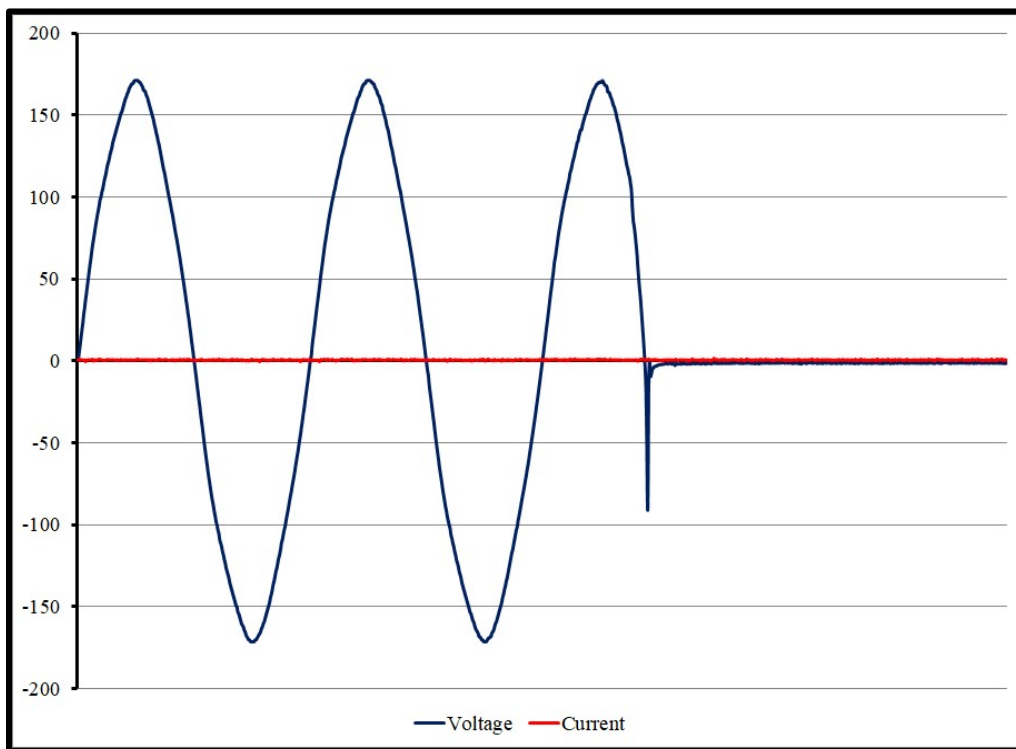


Figure 10. Waveforms of voltage (volts) and current (amperes) during Test 2 of an AFCI circuit breaker at 45 kW/m².



Figure 11. Absence of arc melting produced during Test 3 of an AFCI circuit breaker at 45 kW/m².

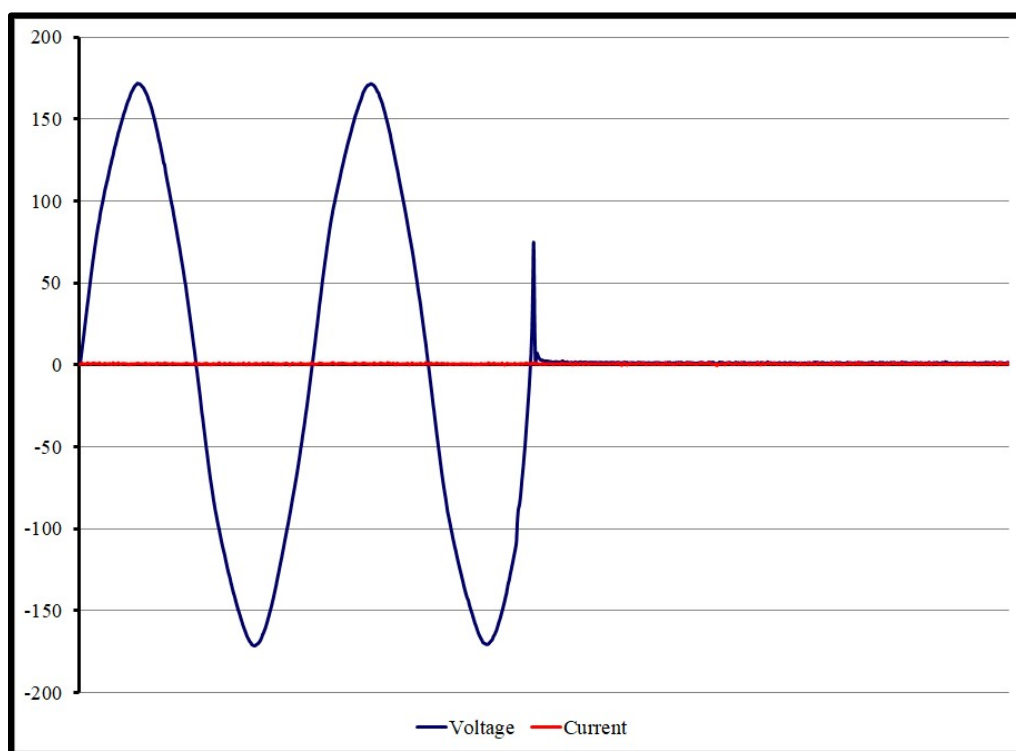


Figure 12. Waveforms of voltage (volts) and current (amperes) during Test 3 of an AFCI circuit breaker at 45 kW/m².



Figure 13. Arc melting produced during Test 4 of an AFCI circuit breaker at 45 kW/m².

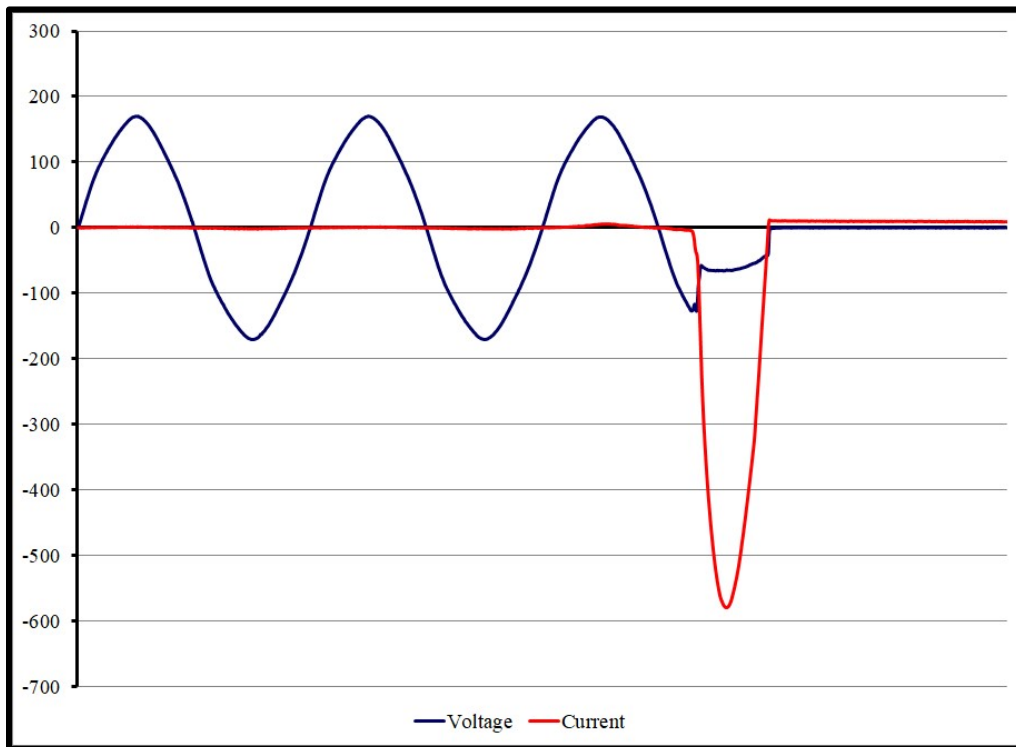


Figure 14. Waveforms of voltage (volts) and current (amperes) during Test 4 of an AFCI circuit breaker at 45 kW/m².

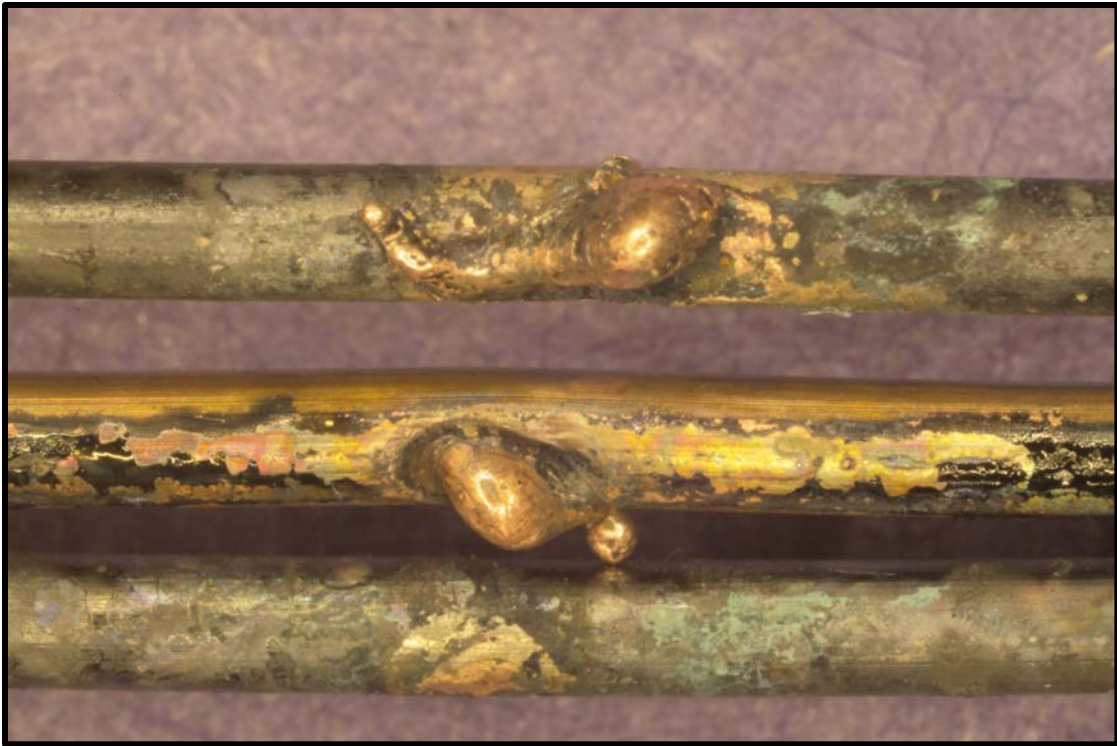


Figure 15. Arc melting produced during Test 1 of an AFCI circuit breaker at 55 kW/m².

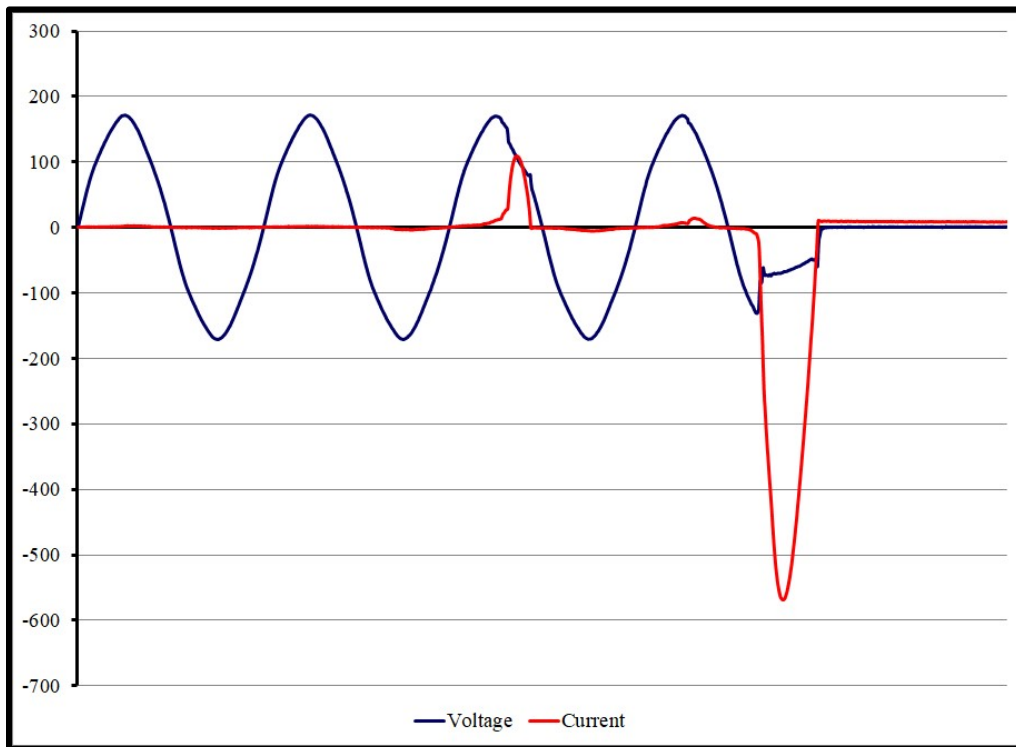


Figure 16. Waveforms of voltage (volts) and current (amperes) during Test 1 of an AFCI circuit breaker at 55 kW/m².



Figure 17. Arc melting produced during Test 2 of an AFCI circuit breaker at 55 kW/m².

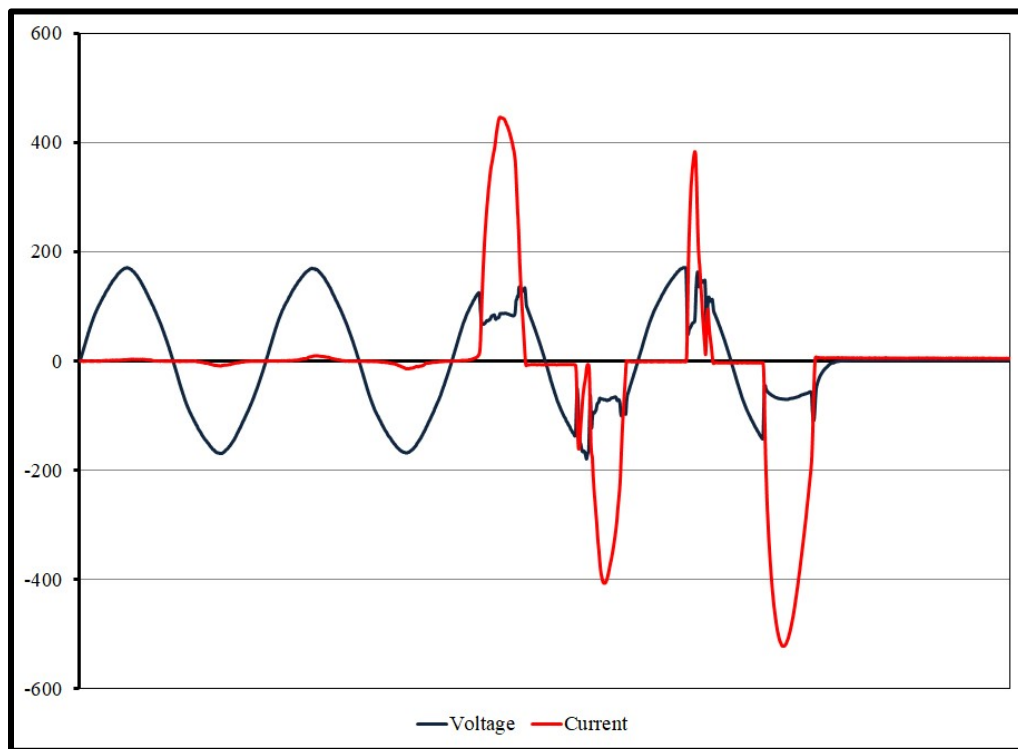


Figure 18. Waveforms of voltage (volts) and current (amperes) during Test 2 of an AFCI circuit breaker at 55 kW/m².



Figure 19. Arc melting produced during Test 3 of an AFCI circuit breaker at 55 kW/m².

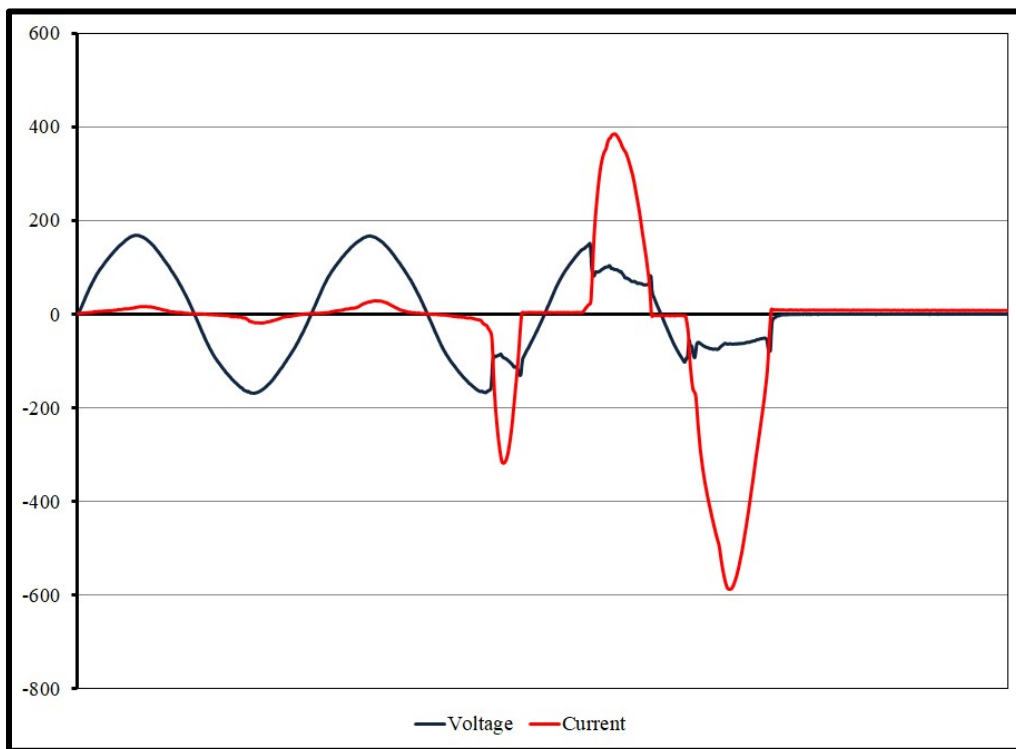


Figure 20. Waveforms of voltage (volts) and current (amperes) during Test 3 of an AFCI circuit breaker at 55 kW/m².



Figure 21. Absence of arc melting produced during Test 1 of a GFCI circuit breaker at 35 kW/m².

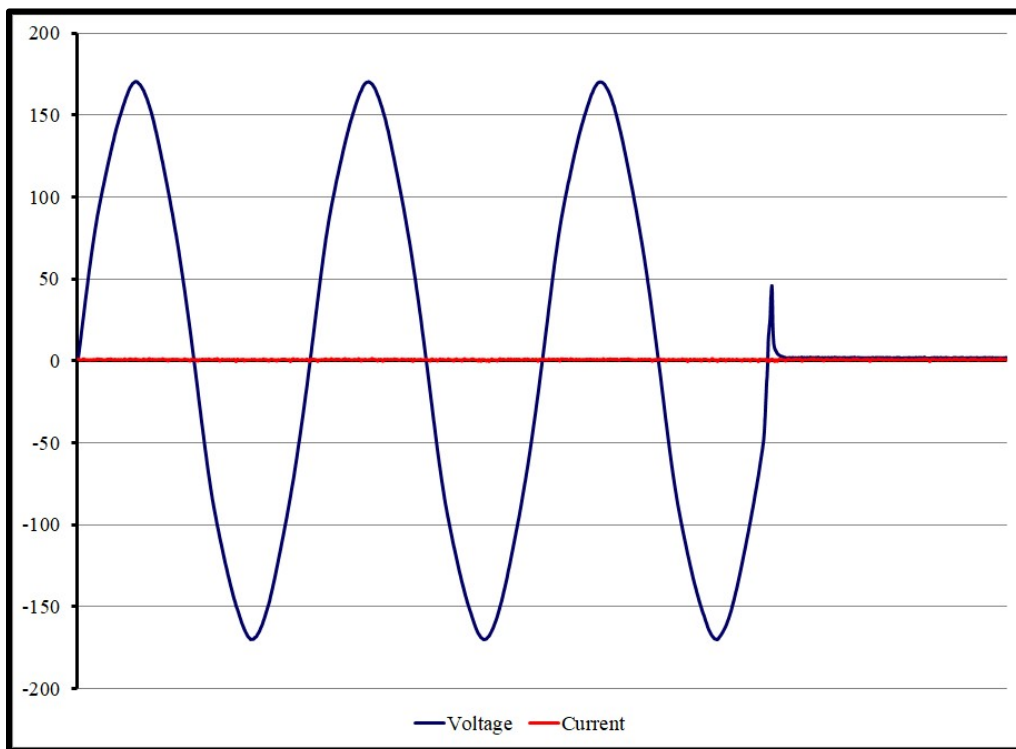


Figure 22. Waveforms of voltage (volts) and current (amperes) during Test 1 of a GFCI circuit breaker at 35 kW/m².



Figure 23. Absence of arc melting produced during Test 2 of a GFCI circuit breaker at 35 kW/m².

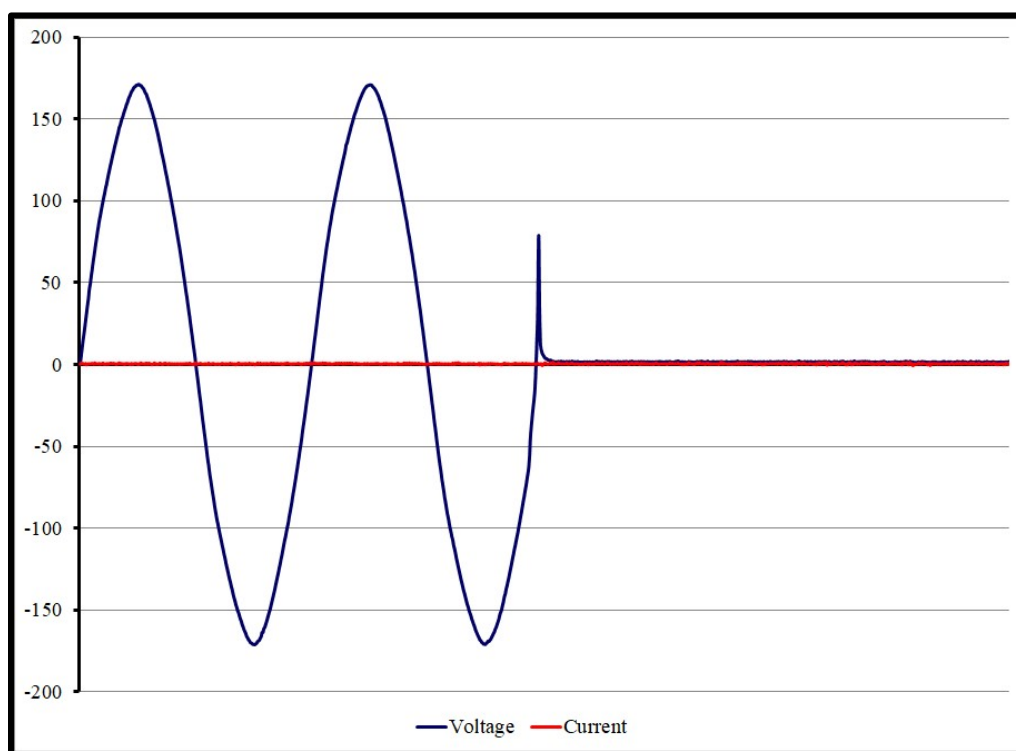


Figure 24. Waveforms of voltage (volts) and current (amperes) during Test 2 of a GFCI circuit breaker at 35 kW/m².



Figure 25. Arc melting produced during Test 3 of a GFCI circuit breaker at 35 kW/m².

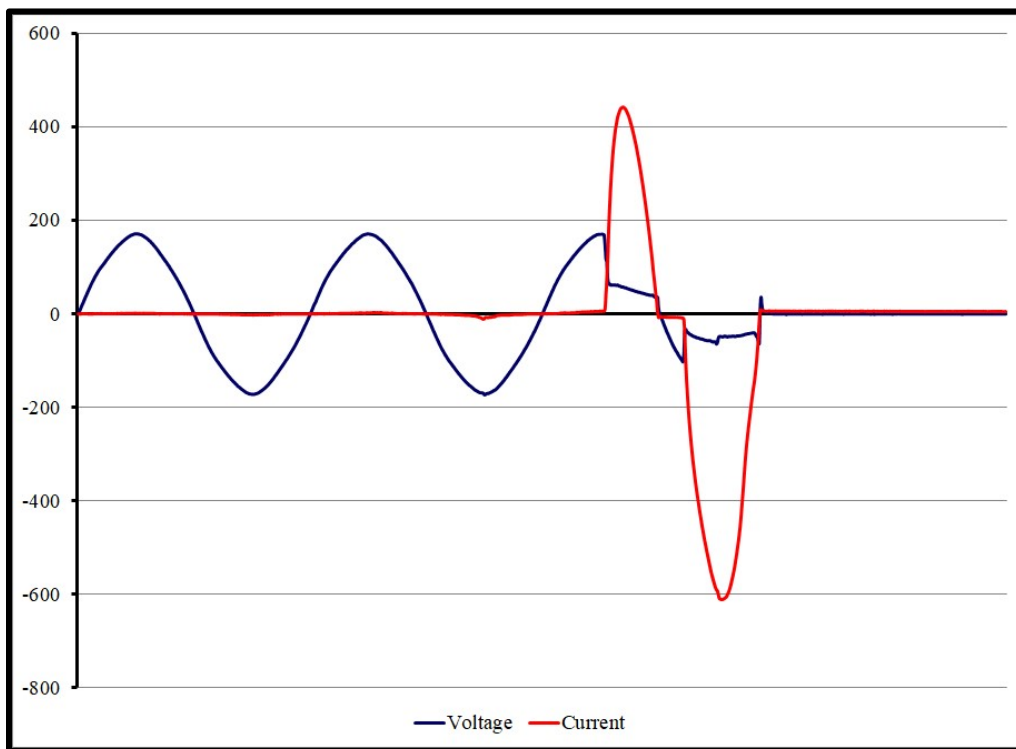


Figure 26. Waveforms of voltage (volts) and current (amperes) during Test 3 of a GFCI circuit breaker at 35 kW/m².



Figure 27. Arc melting produced during Test 4 of a GFCI circuit breaker at 35 kW/m².

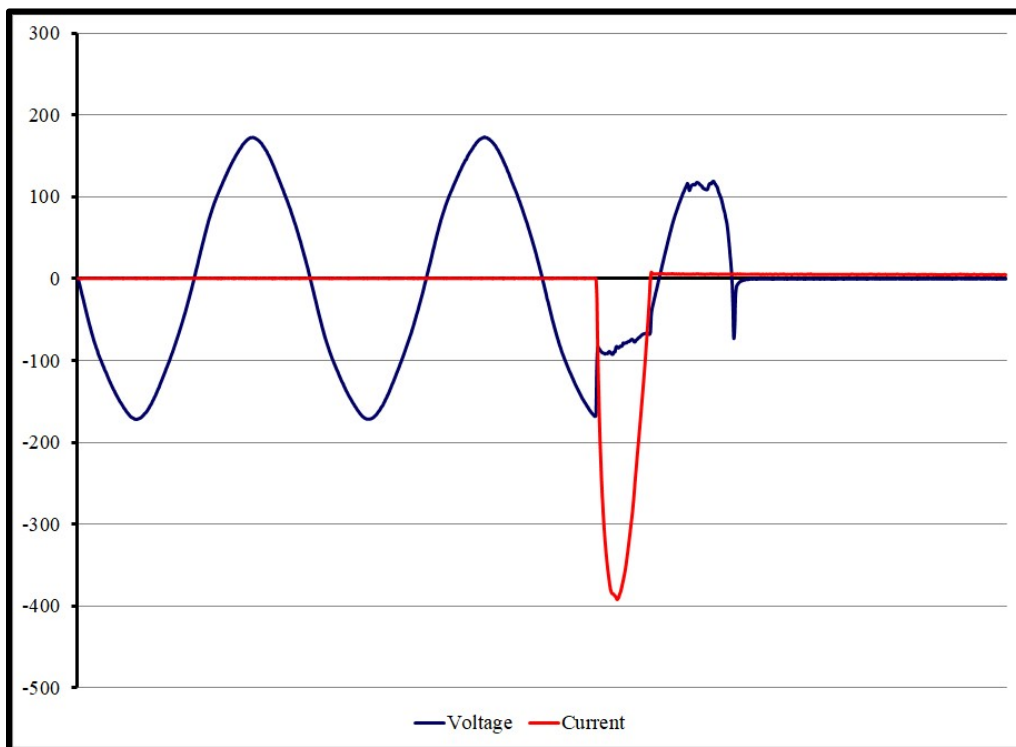


Figure 28. Waveforms of voltage (volts) and current (amperes) during Test 5 of a GFCI circuit breaker at 35 kW/m².

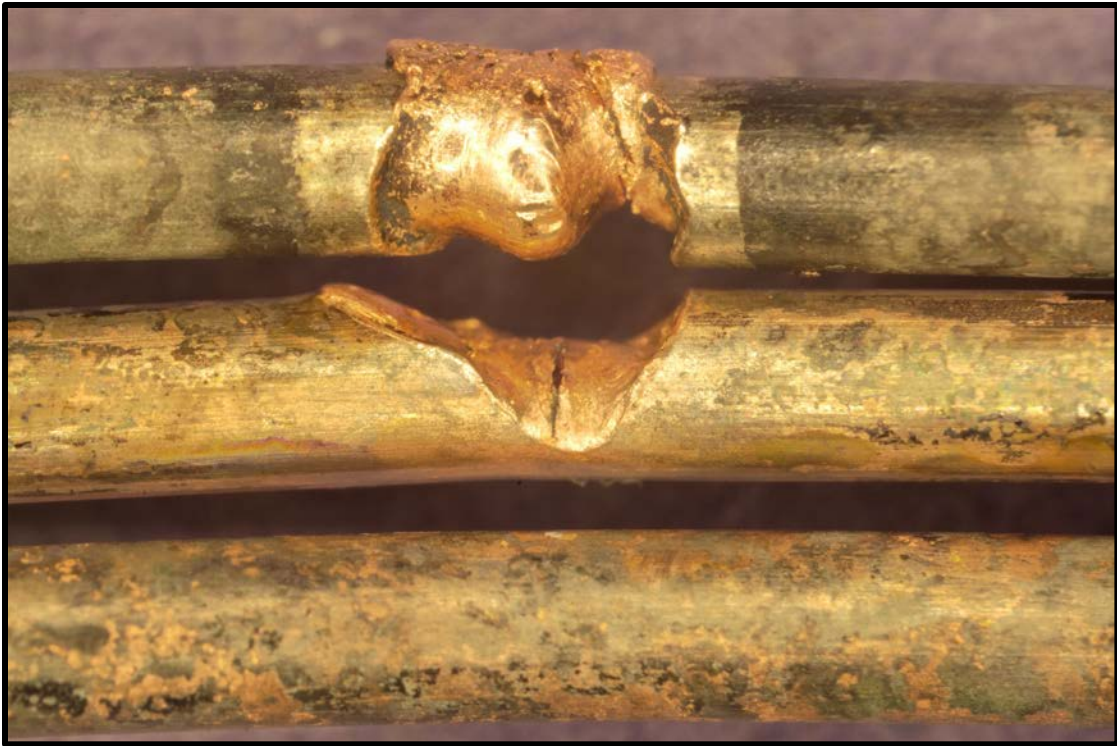


Figure 29. Arc melting produced during Test 1 of a GFCI circuit breaker at 45 kW/m².

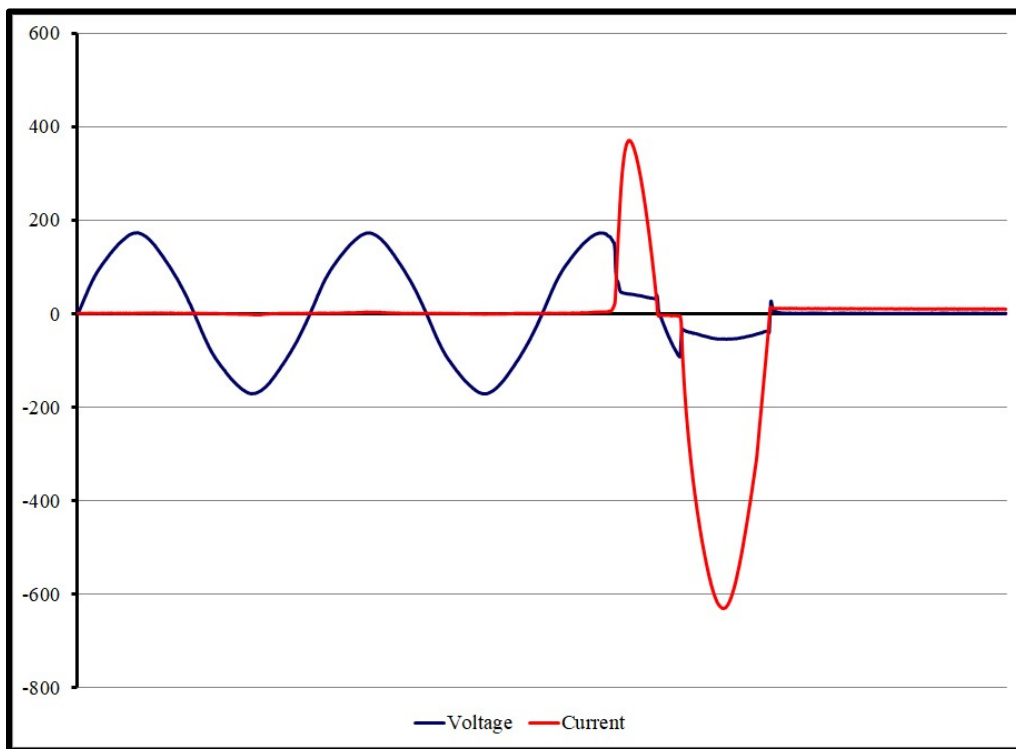


Figure 30. Waveforms of voltage (volts) and current (amperes) during Test 1 of a GFCI circuit breaker at 45 kW/m².



Figure 31. Absence of arc melting produced during Test 2 of a GFCI circuit breaker at 45 kW/m^2 .

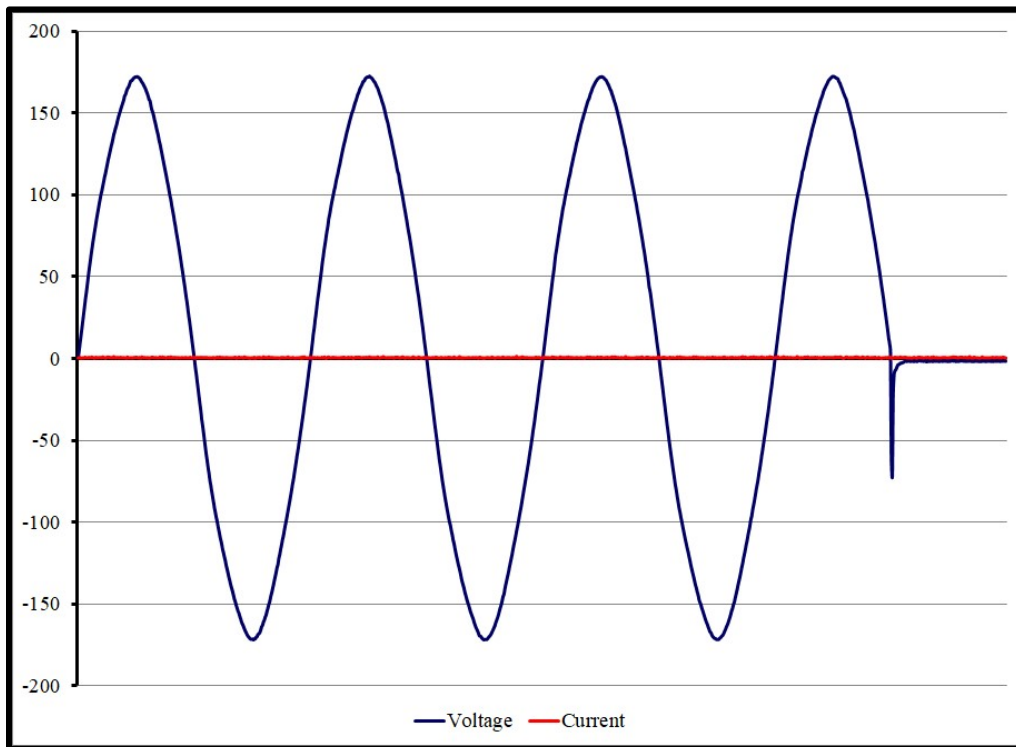


Figure 32. Waveforms of voltage (volts) and current (amperes) during Test 2 of a GFCI circuit breaker at 45 kW/m^2 .

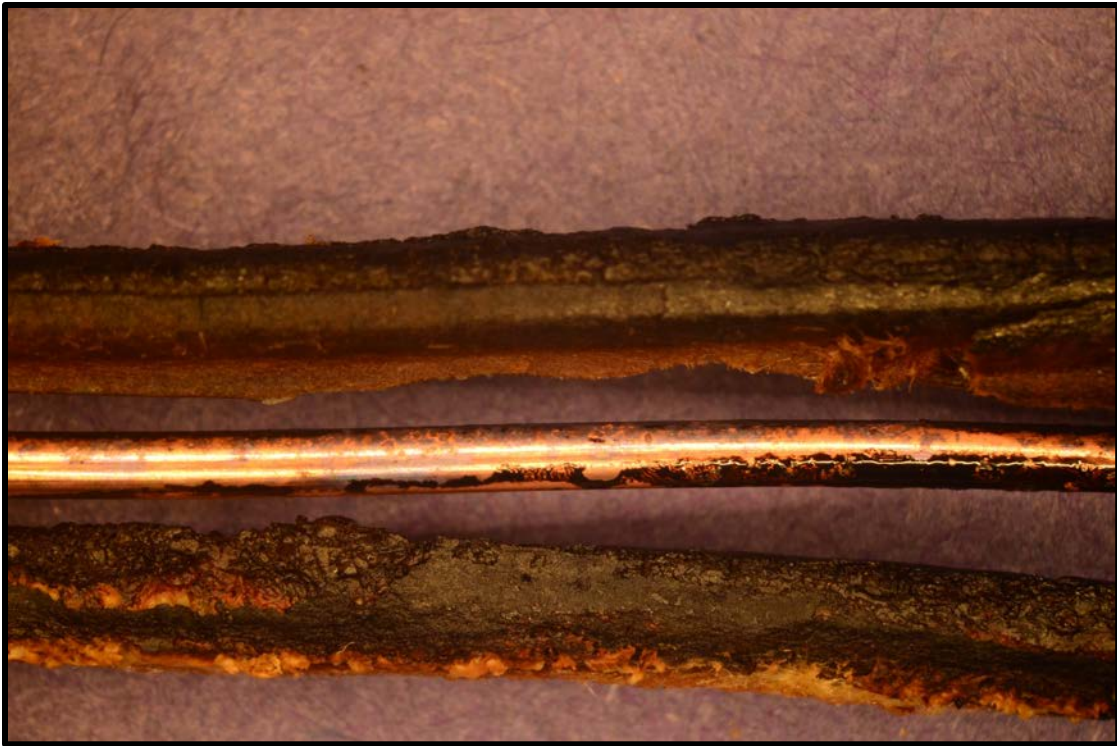


Figure 33. Absence of arc melting produced during Test 3 of a GFCI circuit breaker at 45 kW/m².

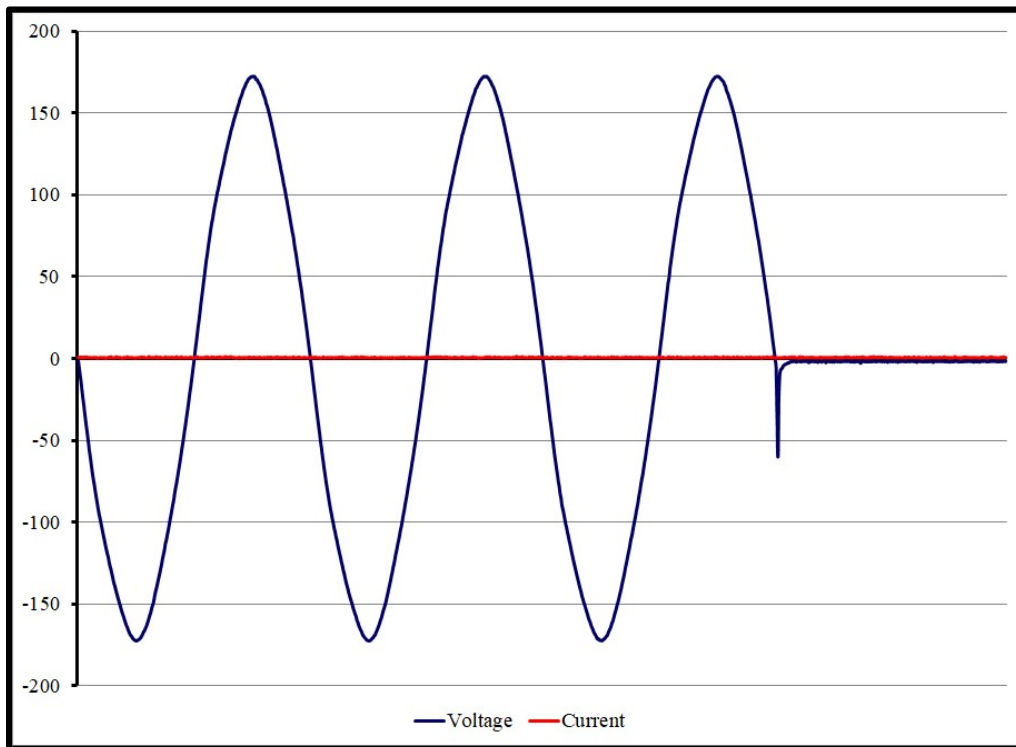


Figure 34. Waveforms of voltage (volts) and current (amperes) during Test 3 of a GFCI circuit breaker at 45 kW/m².



Figure 35. Absence of arc melting produced during Test 1 of a GFCI circuit breaker at 55 kW/m².

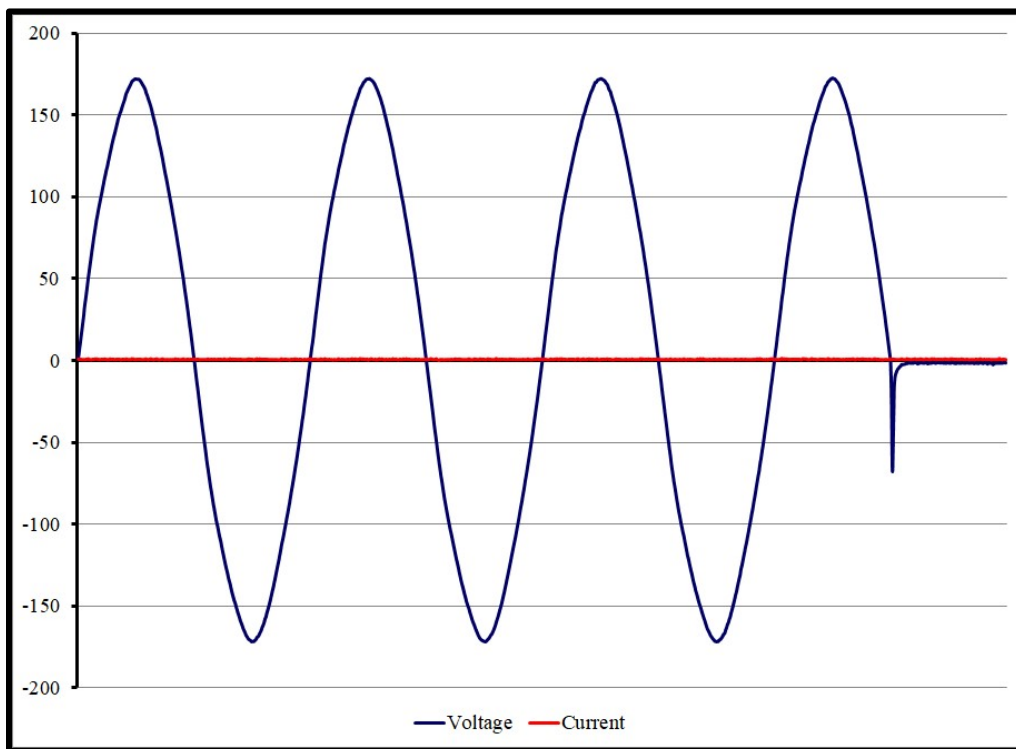


Figure 36. Waveforms of voltage (volts) and current (amperes) during Test 1 of a GFCI circuit breaker at 55 kW/m².



Figure 37. Absence of arc melting produced during Test 2 of a GFCI circuit breaker at 55 kW/m².

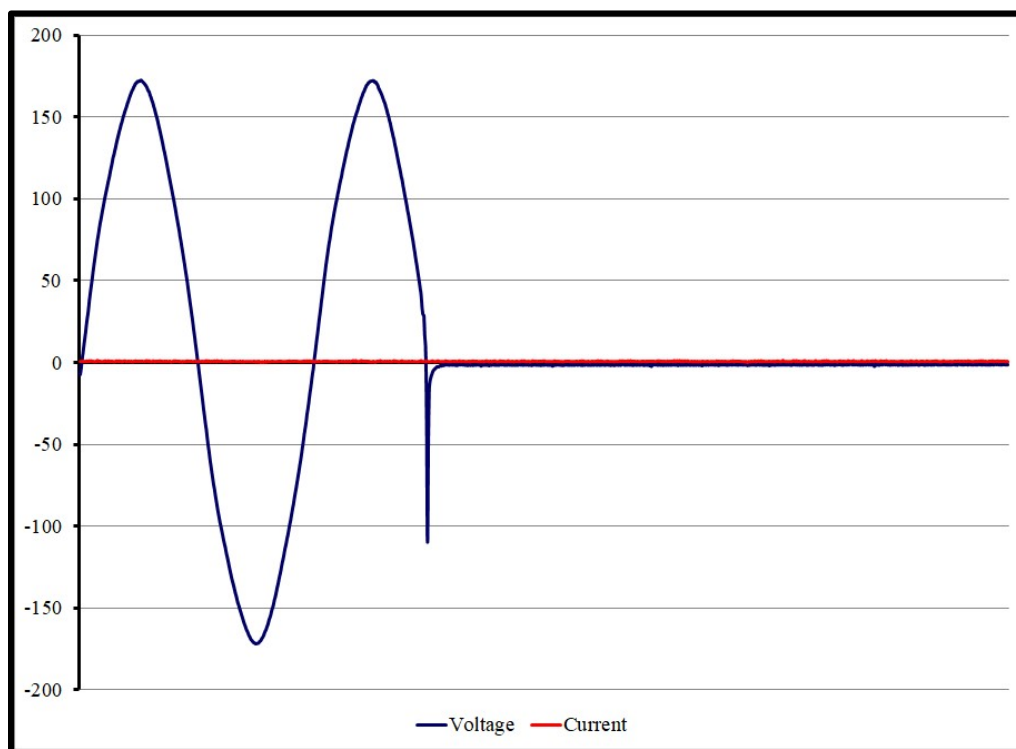


Figure 38. Waveforms of voltage (volts) and current (amperes) during Test 2 of a GFCI circuit breaker at 55 kW/m².



Figure 39. Arc melting produced during Test 3 of a GFCI circuit breaker at 55 kW/m².

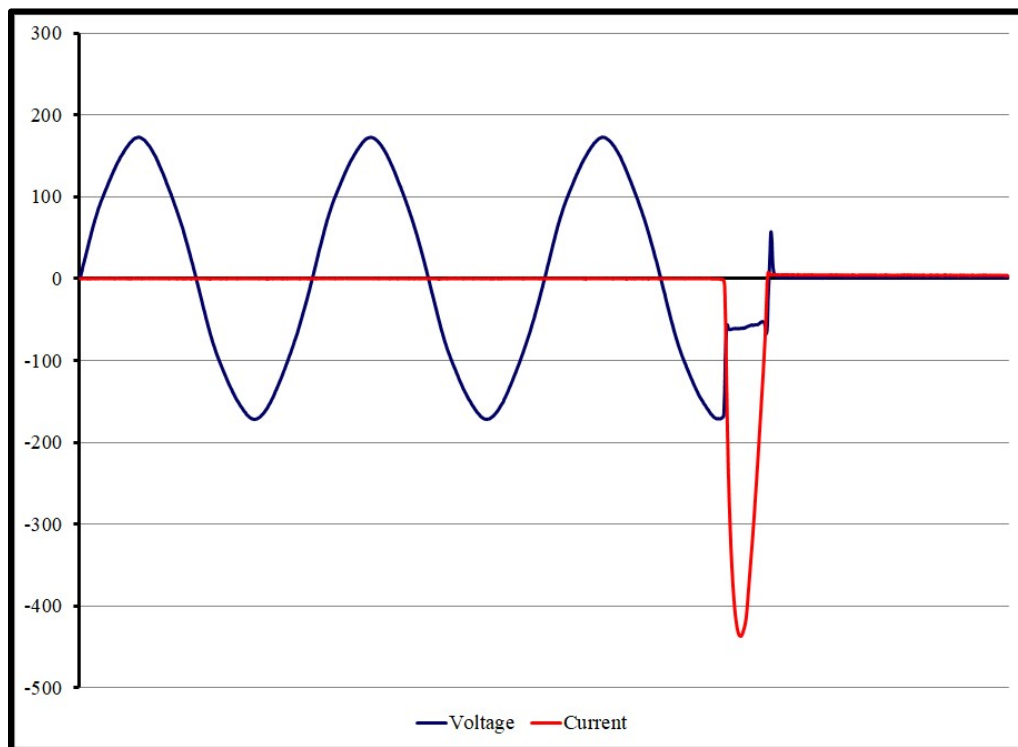


Figure 40. Waveforms of voltage (volts) and current (amperes) during Test 3 of a GFCI circuit breaker at 55 kW/m².

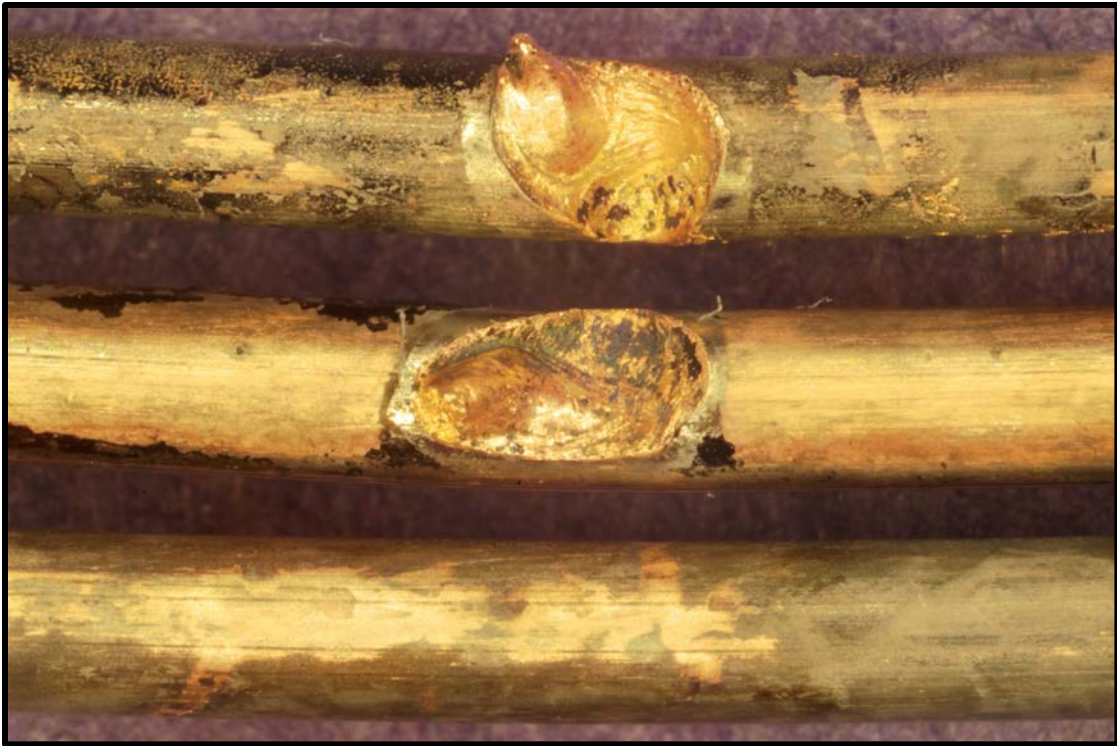


Figure 41. Arc melting produced during Test 1 of a TM circuit breaker at 35 kW/m^2 .

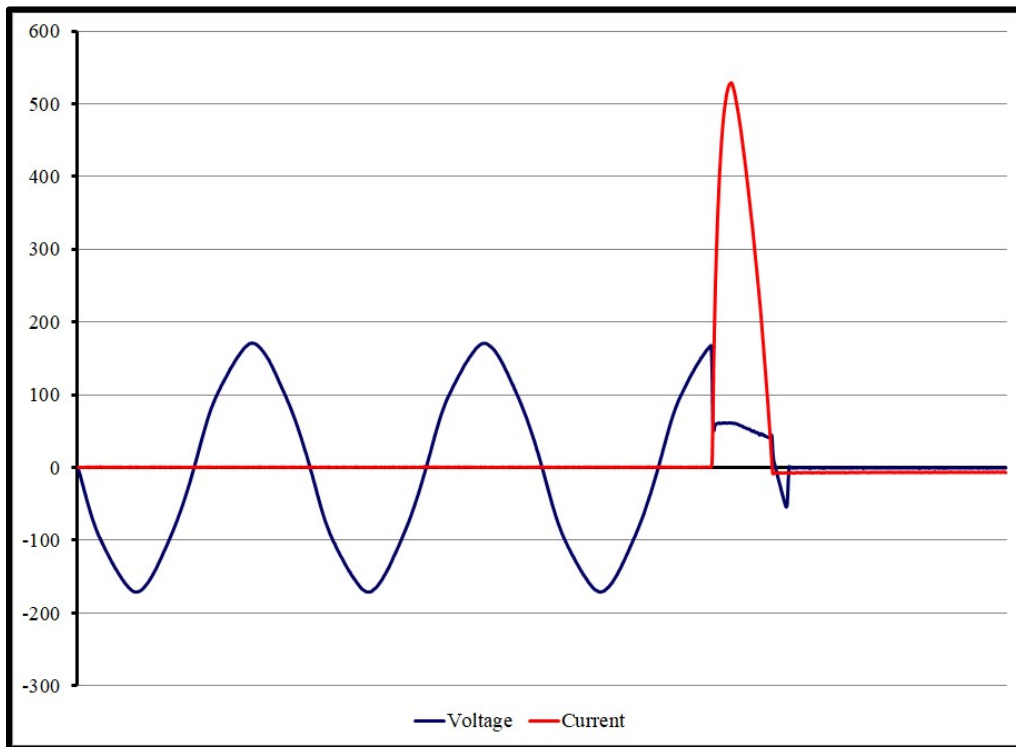


Figure 42. Waveforms of voltage (volts) and current (amperes) during Test 1 of a TM circuit breaker at 35 kW/m^2 .



Figure 43. Arc melting produced during Test 2 of a TM circuit breaker at 35 kW/m^2 .

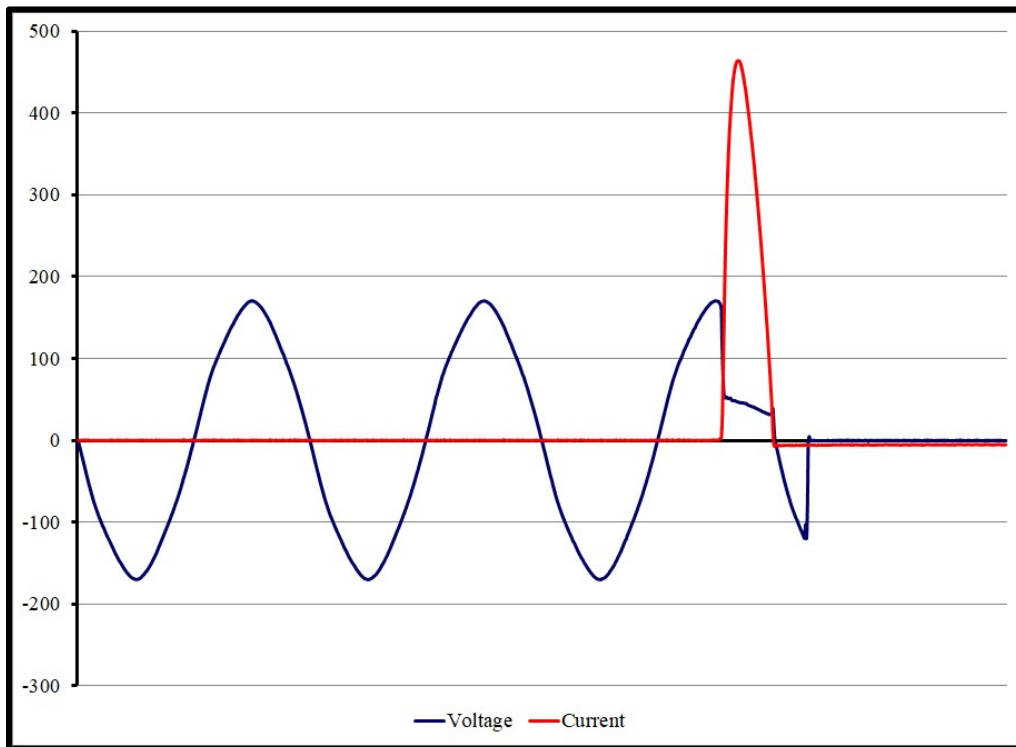


Figure 44. Waveforms of voltage (volts) and current (amperes) during Test 2 of a TM circuit breaker at 35 kW/m^2 .



Figure 45. Arc melting produced during Test 3 of a TM circuit breaker at 35 kW/m^2 .

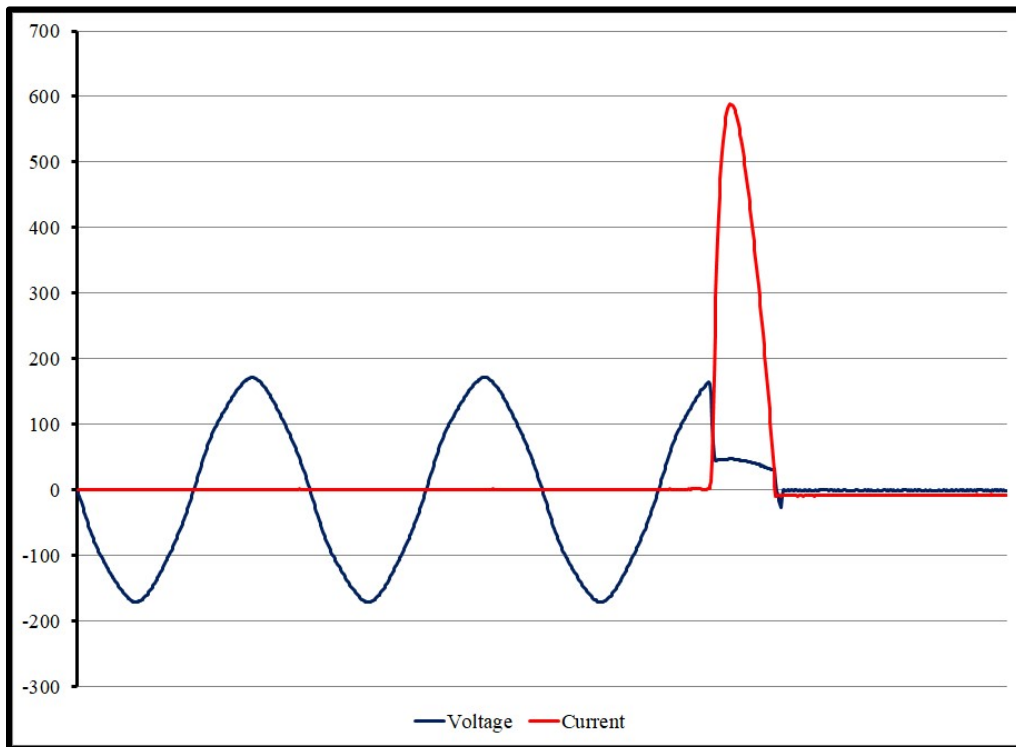


Figure 46. Waveforms of voltage (volts) and current (amperes) during Test 3 of a TM circuit breaker at 35 kW/m^2 .



Figure 47. Arc melting produced during Test 1 of a TM circuit breaker at 45 kW/m^2 .

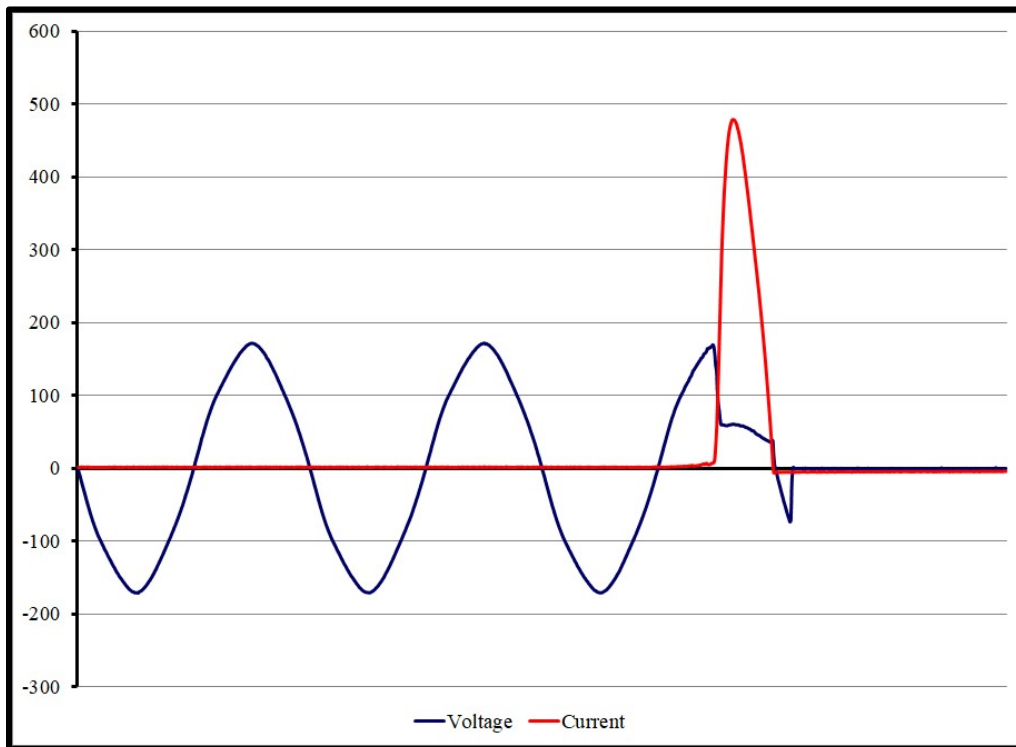


Figure 48. Waveforms of voltage (volts) and current (amperes) during Test 1 of a TM circuit breaker at 45 kW/m^2 .



Figure 49. Arc melting produced during Test 2 of a TM circuit breaker at 45 kW/m².

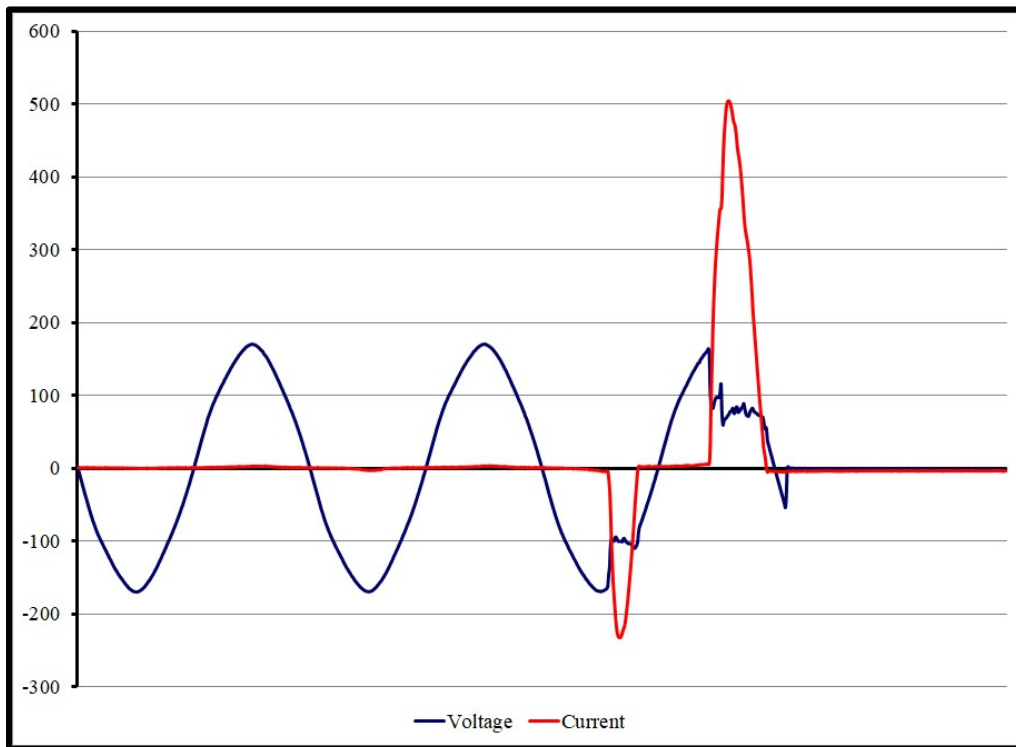


Figure 50. Waveforms of voltage (volts) and current (amperes) during Test 2 of a TM circuit breaker at 45 kW/m².

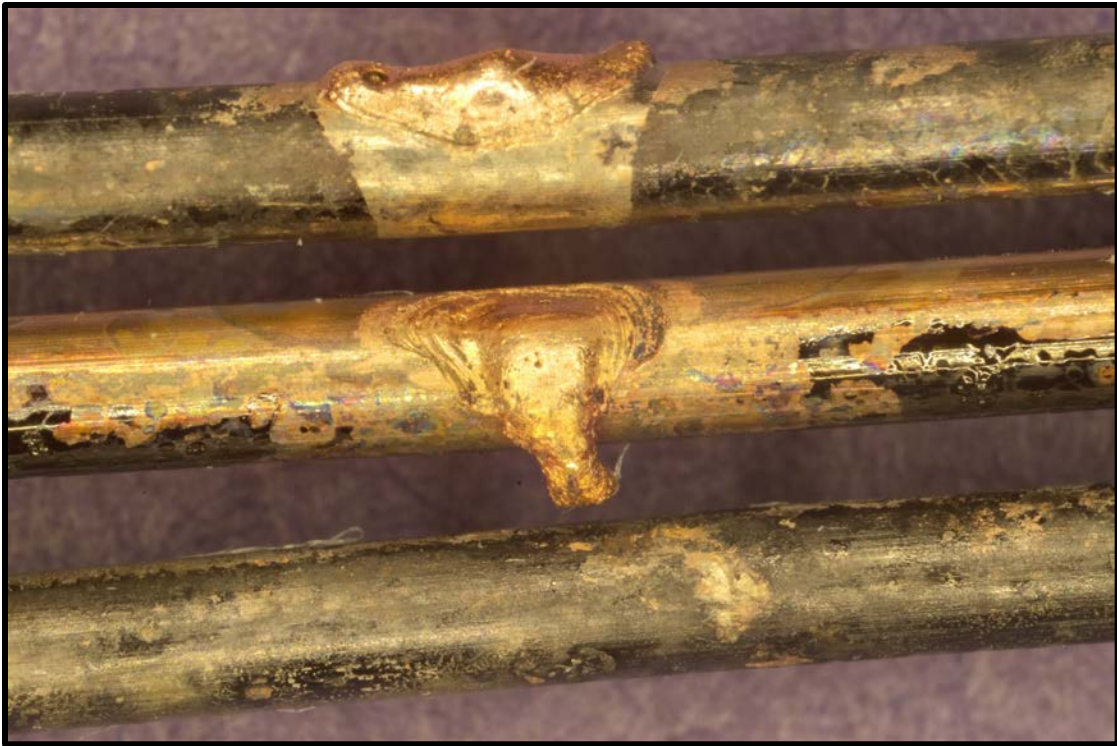


Figure 51. Arc melting produced during Test 3 of a TM circuit breaker at 45 kW/m^2 .

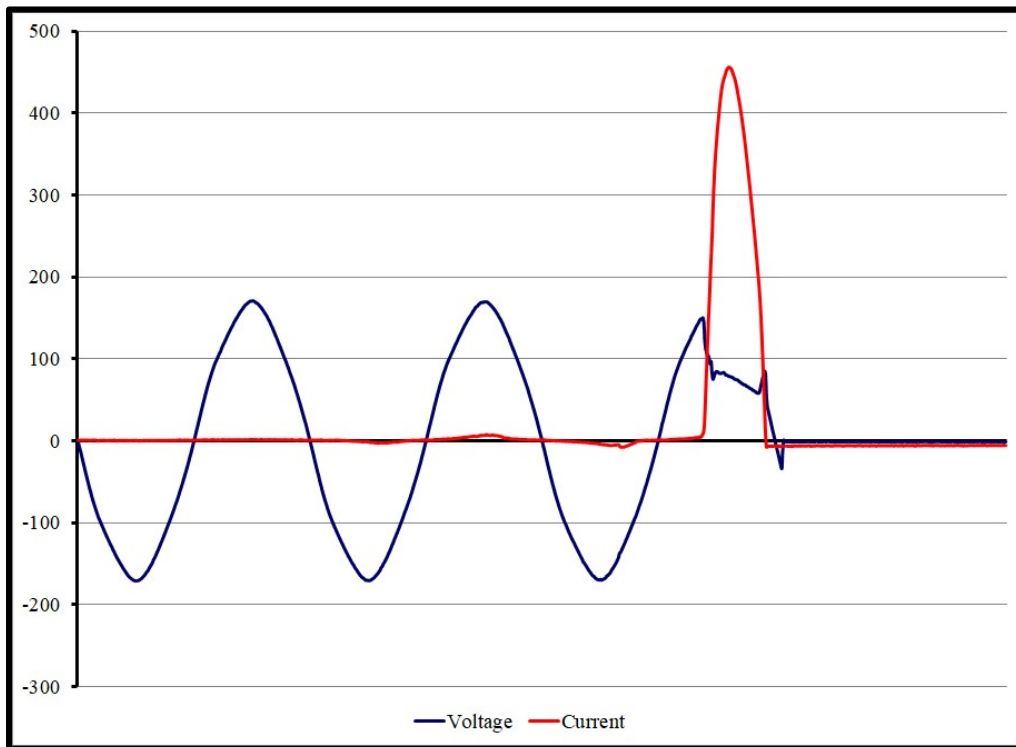


Figure 52. Waveforms of voltage (volts) and current (amperes) during Test 3 of a TM circuit breaker at 45 kW/m^2 .



Figure 53. Arc melting produced during Test 1 of a TM circuit breaker at 55 kW/m^2 .

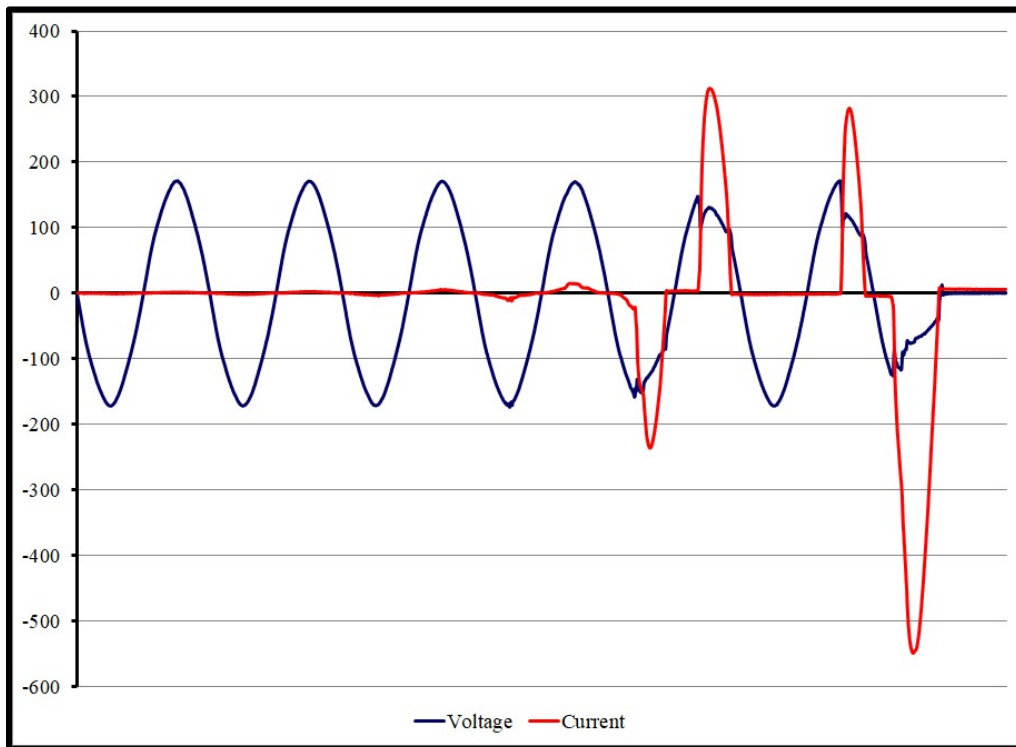


Figure 54. Waveforms of voltage (volts) and current (amperes) during Test 1 of a TM circuit breaker at 55 kW/m^2 .



Figure 55. Arc melting produced during Test 2 of a TM circuit breaker at 55 kW/m^2 .

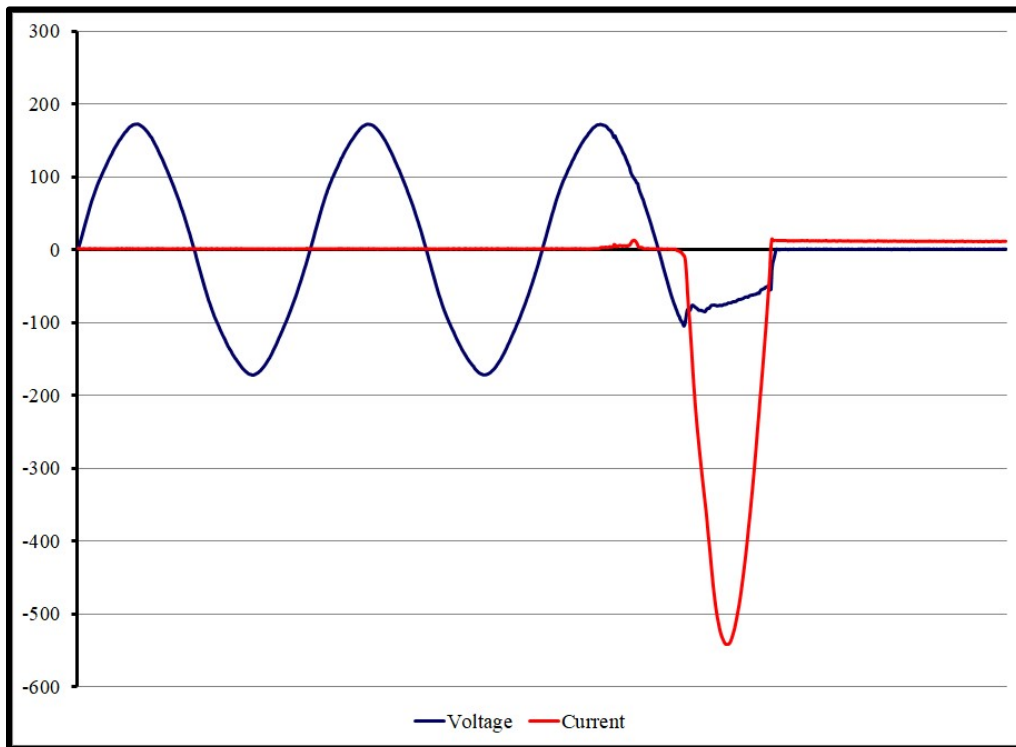


Figure 56. Waveforms of voltage (volts) and current (amperes) during Test 2 of a TM circuit breaker at 55 kW/m^2 .



Figure 57. Arc melting produced during Test 3 of a TM circuit breaker at 55 kW/m^2 .

