NASA TECH BRIEF

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# Self-Healing Fuse

## The Problem:

As electronic circuits become more sophisticated, there is a growing need for more sensitive circuit protection, especially for silicon controlled rectifiers (SCR's) used in certain inverter and bridge applications. Constantly increasing system power levels also require improved circuit protective elements that will absorb the excess thermal energy due to high fault or short circuit currents. The "one shot" operation of conventional fuses make their use undesirable in most remote type applications such as space flight.

## The Solution:

A new circuit protective device, called the self-healing fuse. The self-healing fuse is a very fast-acting current limiting device that provides current overload protection for vulnerable circuit elements and then re-establishes the conduction path within a few milliseconds. This fuse can also perform as a fast-acting switch to clear transient circuit overloads. The self-healing fuse takes advantage of the large increase in electrical resistivity that occurs when a liquid metal vaporizes.

## How It's Done:

The self-healing fuse has a metallic conductor of cross section and length appropriate to the current and voltage rating, much as is the case of any meltable-link fuse. The significant difference is that this conductor is a liquid metal confined in a small channel within a mechanically strong ceramic insulator. The liquid metal fills the fuse channel and the flexible, spring-restrained end reservoirs. The reservoirs provide the mechanical forces that return the liquid to the channel after the fuse fires. The liquid used is mercury; however, sodium, potassium, or a sodium-potassium eutectic (NaK) also have desirable properties for this application.

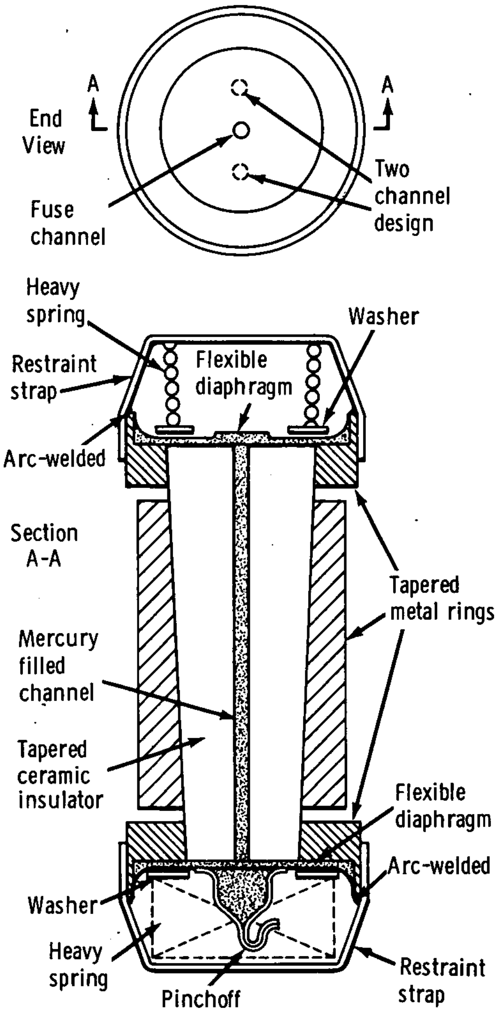
When an overload occurs, the excess current rapidly generates a vapor bubble by heating the liquid metal in the fuse channel. The resultant vapor pressure expels the remaining liquid metal into the reservoirs as a mercury arc discharge is set up along the channel length. The metal vapor arc in the fuse channel dissipates the circuit energy at a low current level until the arc self-extinguishes or until a circuit switch or relay opens the faulted circuit. If the fault is transient in nature, the fuse action should clear the fault without any further action by any other protective devices. Since the arc has an impedance hundreds of times larger than that of the liquid, the fault current level is limited to a value less than rated current. The arc mode typically persists for a time on the order of one millisecond. When the arc extinguishes, the flexible spring-loaded reservoirs return the liquid metal into the conduction channel, thus healing the fuse.

When the fuse fires, very large explosive forces are generated in the closely confined fuse channel. To resist these forces, the ceramic insulator is placed in heavy compression by the external metal structure of the fuse. In the design shown in the figure, the metal rings are shrunk-fit directly over the insulator ceramic. Other basically similar methods of obtaining pre-compression of the brittle insulator materials have been used, such as brazing or glass molding the metal members over the insulator.

The flexible end reservoirs are designed to perform three vital functions: (1) to absorb the impact forces of the liquid mercury being ejected from the channels without permanent distortion; (2) to return liquid mercury to the conducting channel after the arc extinguishes; and (3) to allow for thermal expansion and contraction of the mercury. Therefore, a heavy spring and restraint strap to hold the spring almost fully compressed are added to prevent permanent distortion of the diaphragm and to insure the required restoring forces.

The self-healing fuse uses commercially available sapphire, 99.8+% pure alumina, or high density beryllia of 99.8+% purity for the fuse channels. The external rings are a nickel alloy with a thermal expansion coefficient slightly higher than the ceramic to allow the required precompression during assembly. The flexible end bellows and fill tube are stainless steel. They are arc welded to a lip on the end rings. The fill tube, which is used to evacuate and fill the fuse with mercury, is internally coated with silicon rubber to give a positive seal when flattened, folded, and crimped.

(continued overleaf)



Design for One- or Two-Channel Devices

## Notes:

1. The response to overcurrent is directly proportional to $I^2 t$ (current squared multiplied by a time interval) with a current-time curve almost identical to that for an SCR. Thus the self-healing fuse can be easily designed to protect an SCR, or possibly other semiconductor devices, over a wide range of overload conditions.
2. Life tests were conducted demonstrating a capability of at least 500 operations with fuse ratings from 4 to 40 amperes at 50 to 100 volts dc.
3. Further information is available in the following report:

   NASA CR-121244 (N73-30191), Self-Healing Fuse Development

   Copies may be obtained at cost from:

   Aerospace Research Applications Center
   Indiana University
   400 East Seventh Street
   Bloomington, Indiana 47401
   Telephone: 812-337-7833
   Reference: B74-10004
4. Specific technical questions may be directed to:

   Technology Utilization Officer
   Lewis Research Center
   21000 Brookpark Road
   Cleveland, Ohio 44135
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## Patent Status:

NASA has decided not to apply for a patent.

Source: N.D. Jones, R.E. Kinsinger
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