Fast Fuses

How diffusion pill technology affects fuse time delay characteristics in automotive fuses.

Some electrical loads draw the same current from the time they are turned on until the time they are turned off. But most vehicular loads exhibit inrush or starting surges that may reach many times their steady-state value and may last from a few milliseconds to a substantial part of a second, then settle down to their steady-state value. It is the designer's task to choose a fuse that will protect against a real overload or short circuit, yet not open during the harmless starting surge.
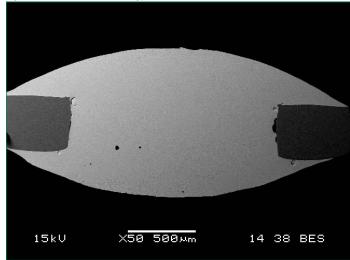
It would seem obvious that a fast-blow fuse would be appropriate for a load without a startup surge, and a slow-blow or time delay fuse for the one with the surge. But not all surges are the same, and not all time-delay fuses are the same. The question is how to match the fuse to the load.

Diffusion pill technology

Littelfuse offers a wide variety of time-delay fuses for automotive and truck applications, including MAXI™ fuse, JCASE® fuse, Low Profile JCASE® fuse, MIDI® fuse, Mega® fuse, and CablePro® fuse. These use diffusion pill technology, developed by Littelfuse, that uses the so-called "M-effect" to produce a controllable time delay.

A fuse that uses diffusion pill technology has a copper fuse element with a tin pellet attached to it (Fig. 1). Copper has a melting point of 1083°C and a very low electrical resistance, while tin melts at 232°C and its electrical resistance is 6.7 times that of copper.

Figure 1: Diffusion Pill Technology

When current levels are normal the fuse element stays cool, but when there is an overload it begins to heat up. When it reaches 232°C the tin begins to melt and diffuse into the copper (the so-called M-Effect), forming an intermetallic alloy whose melting point is lower than that of copper and whose electrical resistance is considerably higher.

This increased resistance causes the fuse element to heat even faster in a thermal runaway effect, and the element quickly becomes hot enough to melt. A gap opens and an arc forms, which rapidly vaporizes the metal until the circuit is broken. By adjusting the sizes of the tin pellet and the copper strip, the

How slow is slow enough?

Selecting a fast-blow fuse is fairly straightforward: Start by choosing a fuse rated to carry about 33 percent more than the expected load (i.e., the normal current should be 75 percent of the expected load current), then adjust for ambient temperature. For example, assume a nominal load of 15 amps and an ambient temperature of 105°C. What should be the rating of a MINI® fuse for this application?

We will use the equation below

$$\text{Ideal fuse rating} = \frac{\text{Normal operating current}}{\text{Temp rerating factor} \times 0.75}$$
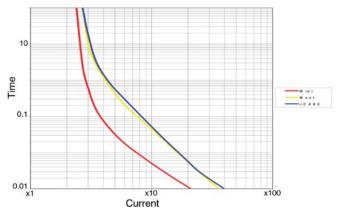
$$= \frac{15A}{0.88 \times 0.75}$$

$$= 22.73A$$

Therefore, a 25A or larger MINI® Fuse should be used.

Selecting a time-delay fuse is a little more complicated. In addition to rerating the fuse for the maximum expected ambient temperature, it is necessary to choose the appropriate time delay characteristics.

As Fig. 2 shows, fuses are available with a wide range of time-delay characteristics. To choose the appropriate time delay for a particular application, first calculate the rating as if a non-time-delay fuse were being used. Then compare the opening time for a particular fuse under consideration with the starting surge of the load: how many amps does it draw, and for how long?
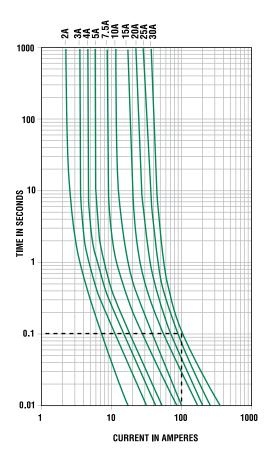
Figure 2: Time-Delay Characteristics of Fuses

For example, Fig. 3 shows that a 30A MINI® fuse subjected to a 100A overcurrent will open in about 0.1 seconds, while a 30A MAXI™ fuse under the same overload will open in about 2.2 seconds. Let us assume that the load draws the same current as in the previous example, but has a starting surge of 50A that lasts for 1 second.

Figure 3: MINI® Fuse T-C Characteristics

MAXI™ fuse gates (Maximum/Minimum Opening Times)

% of rating	20A	25A	30A	35A	40A	50A	60A	70A	80A
135	1800	1800	1800	1800	1800	1800	1800	3600	3600
	60	60	60	60	60	60	60	60	60
200	20	30	30	40	40	50	60	60	60
	4	4	6	6	8	10	15	4	4
350	2	4	4	5	5	6	7	2	2
	0.7	0.7	1	1	1.4	1.7	2	0.20	0.20
600	1	1	1	1	1	1	1	1	1
	0.15	0.15	0.20	0.20	0.20	0.20	0.20	.1	.1

The tables below give gate values for other Littelfuse time-delay automotive fuses.

MIDI® fuse gates (Maximum/Minimum Opening Times)

% of rating	30-125A	150-200A
100		
	100 h	
110		
	4 h	
150	1 hr	
	90 s	
200	100 s	15 s
	5 s	1 s
300	15 s	3 s
	0.5s	0.3 s

We use the same calculation as with the MINI® fuse, to determine that the basic rating of our fuse should be 25A. While we used the delay curves as a preliminary indication it is important to know that such curves are averages and not guaranteed; for guarantees we use tables of maximum and minimum delay values (also called time-current gates or TC gates). We can see in the table below that a MAXI™ fuse rated at 25A will carry 200 percent of its rated load for a minimum of 4 seconds and a maximum of 30 seconds, so it is a good choice in this application.

JCASE® fuse gates (Maximum/Minimum Opening Times)

% of Rating	Opening Time Min / Max (s)
110	100 h / –
135	60 s / 1800 s
200	4 s / 60 s
350	200 ms / 7 s
600	40 ms / 1 s

Fast Fuses

Fast fuses versus slow: How do you choose?

Thermal cycling

Thermal cycling applies to all fuse technologies and in fact to all materials but may be considered especially important to fuses with the active mechanism of diffusion pill technology. While the diffusion pill design makes for a very effective time-delay fuse, what happens if the overcurrent does not last long enough to blow the fuse? Each time a short overcurrent pulse flows through the fuse the element will heat up, and some tin-copper diffusion will take place, permanently changing the characteristics of the element. With enough pulses the fuse will eventually fail. If there is some question as to whether a particular fuse type will survive in a pulsed application, then it is best to perform an I2T analysis. I2T ("I squared T"), expressed in ampere2 seconds is a measure of the total energy dissipated in the fuse during a pulse. This involves calculating the ratio of the applied I2T to the fuse's nominal melting I2T, then looking at the table below and Fig. 4.

Pulse cycle withstand capability

Number of pulses	Percent of nominal I2T
100,000	22
1000	38
100	48
600	40 ms / 1 s

Littelfuse provides a separate application note that provides full instructions on doing an I2T analysis.