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MEMORANDUM

To: Whom it may concern
From: iMaXX Technical Department Year: 2024

Subject: Automotive fuse performance and selection.

SUMMARY

FUNCTION:
A fuse in an electrical circuit will prevent an overload current to cause damage to the circuitry, such as wires or PCB tracks, by irreversible switching off the current. The fuse operates due to the fact that the measure of current passing through the fuse element generates heat in this element caused by the fuses element's internal resistance. The amount of heat produced is proportional with the amount of current passing based on changes in the electrical resistivity and conductivity for a given material, determining the electrical and thermal performance of that material. Because load bearing circuitry behaves very similar to a fuse (heating up under operation with increased temperatures for higher current levels), it is important to avoid current levels which would cause damage to the circuitry and potential fire hazards. This is achieved by including a fuse in such circuit as the intended weak link, opening the circuit in a controlled manner at a current level suitable for the application, considering all variables and parameters.

OPERATION:
The thermal energy stored in the fuse element will partially dissipate through the fuse blades and receptacles, into the attached circuitry, as well as into the surrounding air. Considering the total heat dissipation in an energized circuit, a delicate balance of element temperature versus current level will be established. When current is increased to a level where the element reaches its melting temperature, the fuse will open the circuit and disconnects it from the power source.

APPLICATION:
For a given application, the load bearing circuitry cross section is determined based on continuous current levels to be expected, while taking into account the duration and magnitude of the in-rush or starting current. The application ambient temperature is also of importance because of its impact on the current carrying capacity of the conductor or cable. The heat generated by the current flowing through the circuitry, in addition to the heat resulting from the application's ambient temperature, should not lead to a softening or melting of materials. For example: the permissible working temperature of PVC insulated single core cable is limited to approx. 70°C, whereas certain types of cross-linked insulation materials for wiring used in automotive applications have significant higher melting temperatures, allowing use in ambient temperatures of up to 120°C.

FUSE PERFORMANCE:
In order to qualify and compare fuse performance, a number of international standards exist such as the JASO, ISO 8820, SAE and UL as well as a number of vehicle manufacturer specific standards. All these standards have in common that the fuse is evaluated under standardized

conditions, not necessarily resembling the application. The fuse is always tested using a standard test module, using specific lengths and cross-sections of cable, in a constant temperature and otherwise controlled environment, gathering objective test data to qualify the performance of the fuse. Doing it any different than strictly following these conventions, results in measuring more than just the fuse (such as the impact of the fuse holder, its contacts, contact crimp quality, dissipation, etc.) and would lead to confusion in evaluating published data between fuse ratings, types or makes. Therefore it is required to consider the application parameters separately when selecting a fuse.

FUSE SELECTION:
As is the case with the circuitry, the application temperature of the fuse is also an addition of the heat generated by the fuse and the heat from external sources. Whether the fuse heats up from being installed in an engine compartment (adversely affecting the heat dissipation from the fuse) or from running electrical current, once the element's physical melting temperature is reached, the fuse will open the circuit. With the iMaXX blade fuse series, where the conductive material is zinc (Zn), a melting temperature of 420°C is a fixed and absolute parameter.

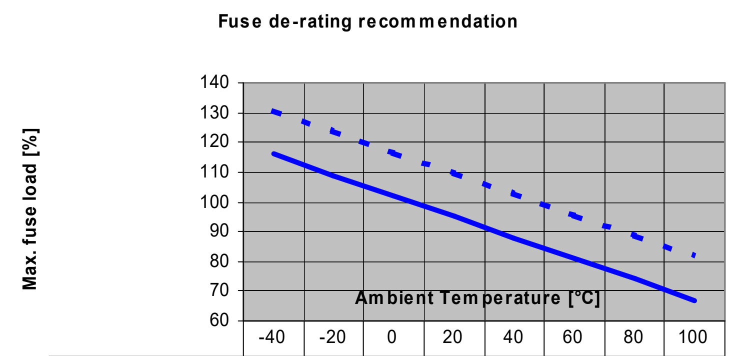
RATING SELECTION:
Even it is not clearly mentioned in the ISO 8820 part 3 and other parts of this international standard, the continuous current of a blade fuse should not exceed 80% of the nominal current at an environmental temperature of 25°C.

Based on the laboratory standardized test results (reference ISO 8820-3) a normOTO blade fuse will hold a 110% load (continuous current) for a minimum of 100 hours, whereas the fuse will have to open at an overload of 135% between 0.75 and 600 seconds. In the application other parameters will affect the fuse performance such as temperature, duty cycle, inrush current, etc., to be evaluated separately. Key is to select the rating such that the application circuitry is protected against overheating, while considering that the current carrying capacity of the fuse is affected by application parameters. Example: a given cable (length, cross section, insulation) can conduct a continuous current of 17A at 25°C, it seems appropriate to fuse such circuit with a 15A fuse. However, this 15A fuse will carry 110% or 16.5A at 25°C almost indefinitely (assuming the fuse holder is comparable with the test holder used in the lab), while it is only guaranteed to open the circuit at 135% or 20.25A. The question then becomes how much reserve is in the cable specification and what temperature the cable will reach when subjected to 20.25A. Another possibility is the use of a 10A fuse, which will open at 13.5A (135%), a safe margin under the cable specification. Assuming that the application device draws less than 10A continuous, the choice of a 10A fuse may work well, provided that a margin is used to deal with the effects of inrush currents, duty cycle and fuse de-rating.

Additional information on the selection of the right fuse and right cable dimension is mentioned in the ISO 8820 part 2.

DE-RATING:

For reasons mentioned earlier, the fuse has to be de-rated for use in elevated temperature environments. Using the 10A fuse in the example application, but now at 80°C, assuming that the cable and device are not affected by this temperature change (which in reality they are), the fuse will at some point open the circuit, even under normal current load conditions. The incremental heat from the ambient adds to the heat generated by the nominal 10A current, leading to a condition where the fuse element will reach its melting temperature, despite the fact that the load is within the fuse rated current. The graph provides a rule of thumb to apply temperature effects on fuse rating selection. The dotted line depicts the standard lab conditions where the reference is 110% load at 20°C, with all other variables controlled. The solid line represents an average based on experience, applicable to applications with a number of non-controlled variables, placing the reference at 95% for 20°C. Reading from this second line, the maximum load at 80°C is shown to be 74% of rated current. In the 10A example this would mean that the fuse is not to be operated at continuous currents of over 7.4A, in other words the 10A fuse has become a 7.4A fuse, hence the term de-rating. When running a 10A current anyway, an overload of actually 10.0 / 7.4 or 135% is applied, causing the fuse to open the circuit.



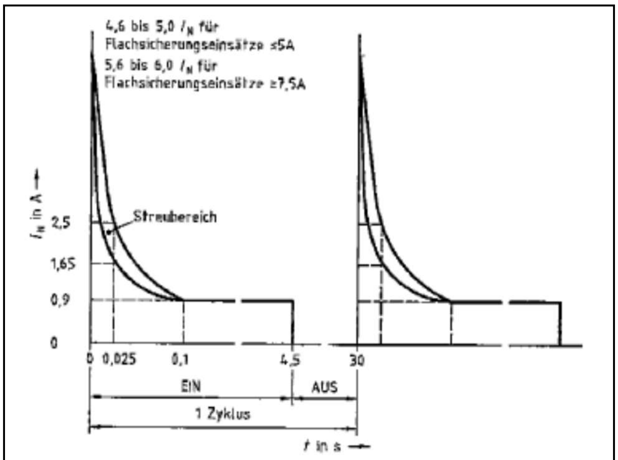
	-40	-20	0	20	40	60	80	100
Lab. load [%]	131	124	117	110	103	96	89	82
Appl. load [%]	116	109	102	95	88	81	74	67

FUSE RESPONSE TIME:

The time in which a fuse must respond to a specified overload condition is specified in the mentioned standards. Besides the 110% and 135% loading discussed before, specifications are provided for 160%, 200%, 350% and even 600%; the higher the current load, the faster the fuse will respond. The characteristic of the fuse (or a series for that matter) is detailed in a TC (Time-Current) curve, also referred to as It curve (where I is the symbol used for current and t the symbol used for time). This curve is discussed in a separate document. Essential to know here is that one 10A fuse is not like another type of 10A fuse, where characteristics can vary from "very fast acting" to "time delayed" performance, simply by varying the fuse element design. Typically more mass in the fuse element requires more thermal energy to bring it to its melting point, delaying the response time to overload. Similar is the effect of moving coolant air around the element or applying larger cross section cable, both of which dissipate or drain thermal energy from the element, requiring larger amounts to reach its melting temperature. For particular load types, such as motors with relatively high in-rush or starting currents, a time-delayed performance is preferred to avoid nuisance or undesired opening of the fuse.

IN-RUSH CURRENT:

Few electrical devices will draw their nominal design current immediately after being switched on. Typically a current level significantly higher than the nominal current is required to start a motor or to light a (initially cold) light bulb filament. The ISO 8820 standard provides a section to evaluate fuse performance in this area. This test exposes the fuse to an in-rush current between 560 and 600%, falling to nominal in 0.1 seconds, while remaining at this level for another 4.4



seconds. This is followed by a 25.5 seconds of no load, after which the cycle starts again for a total of 50000 cycles, in which the fuse shall not open the circuit.
If the application's in-rush current is either significantly higher or the duty cycle is more severe (in the standard the duty cycle is 4.5 seconds on-time in a 30 second cycle, or 15%), the fuse rating selection should be reconsidered from this perspective. Such conditions may also prompt for using a time delayed fuse such as a maxiOTO or megaOTO series fuse rather than using a fast acting normOTO or miniOTO blade fuse series.

FUSE DESIGN LIMITATIONS:
Working within the industry standards, the fuse manufacturer has little flexibility in shifting the fuse characteristics. Although the 135% requirement seems to be rather wide (requiring opening between 0.5 and 600 seconds), the typical performance of the iMaXX F1500 series normOTO is on the quicker side. Making it more time delayed, for example towards 5 minutes (300 seconds) would be well within the standard's requirements, but would result in failing to meet the specified opening times at 160, 200, 350 or 600%, becoming too slow acting. Another aspect to consider here is that many of the ISO 8820 tests, such as the in-rush current described above, require that the fuse after being tested still meets the requirements of voltage drop or 135% load testing. Because many cycling and environmental tests have an ageing effect on the fuse element, causing a fusing performance shift, the element design needs to anticipate meeting the initial criteria even after being subjected to serial testing. This in turn also implies that a fuse used in an application for a number of years, will perform to specifications, as would a new fuse of the same type.

SUMMARY:
Selecting the right fuse for an application goes well beyond simply matching the rated current to the nominal application current. As reviewed in this synopsis, the most important variables to consider and evaluate are:

- Circuitry cross section selection, based on:
  - Device electrical load
  - Mechanical aspects
  - Length of circuit
- Fuse initial rating selection, based on circuitry load capacity
- Fuse "de-rating" for elevated ambient temperatures
- Fuse "time-current" considerations
- Evaluation of in-rush currents

Furthermore a range of other aspects should be reviewed in the application's design or project phase, amongst which:

- Mechanical aspects (vibration, mechanical loading, dimensions and tolerances)
- Environmental aspects (humidity, condensation, salt spray, contamination)
- Temperature aspects (temperature shock, durability)

Although the fuse is subjected to a large number of these types of tests in its product validation phase, conditions in the application may differ to such extend that reviewing these aspects is required.

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