Using TRM Sensors Hydrocarbon Probes
In Hazardous Areas

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Report # TRM 1708-1

February 21, 2017

Test Performed and Reported by:____________________

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TRM Sensors are “simple apparatus”. They can be installed in classified areas up to CID1 and Zone 0 as long as the monitoring device and circuit energizing the sensor probe is intrinsically safe.

Discussion:

North American and international standard provide the definition for simple apparatus including National Electrical Code, NFPA 70 – 2014 edition, article 504:

Simple Apparatus. An electrical component or combination of components of simple construction with well-defined electrical parameters that does not generate more than 1.5 volts, 100 mA, and 25 mW, or a passive component that does not dissipate more than 1.3 watts and is compatible with the intrinsic safety of the circuit in which it is used.

Informational Note: The following apparatus are examples of simple apparatus:

(1) Passive components; for example, switches, junction boxes, resistance temperature devices, and simple semiconductor devices such as LEDs
(2) Sources of stored energy consisting of single components in simple circuits with well-defined parameters; for example, capacitors or inductors, whose values are considered when determining the overall safety of the system
(3) Sources of generated energy; for example, thermocouples and photocells, that do not generate more than 1.5 volts, 100 mA, and 25 mW

And from the IEC 60079-11:2011 (and EN 60079-11:2012) clause 8.7 defines simple apparatus:

5.7 Simple apparatus

The following shall be considered to be simple apparatus:

a) passive components, for example switches, junction boxes, resistors and simple semiconductor devices;
b) sources of stored energy consisting of single components in simple circuits with well-defined parameters, for example capacitors or inductors, whose values shall be considered when determining the overall safety of the system;
c) sources of generated energy, for example thermocouples and photocells, which do not generate more than 1,5 V, 100 mA and 25 mW.

Simple apparatus shall conform to all relevant requirements of this standard with the exception of Clause 12. The manufacturer or intrinsically safe system designer shall demonstrate compliance with this clause, including material data sheets and test reports, if applicable.

The following aspects shall always be considered:

- simple apparatus shall not achieve safety by the inclusion of voltage and/or current-limiting and/or suppression devices;
- simple apparatus shall not contain any means of increasing the available voltage or current, for example DC-DC converters;
- where it is necessary that the simple apparatus maintains the integrity of the isolation from earth of the intrinsically safe circuit, it shall be capable of withstanding the test voltage to earth in accordance with 6.3.13. Its terminals shall conform to 6.2.1;
- non-metallic enclosures and enclosures containing light metals when located in the explosive atmosphere shall conform to the electrostatic charges on external non-metallic materials requirements and metallic enclosures and parts of enclosures requirements of IEC 60079-0;
- when simple apparatus is located in the explosive atmosphere, the maximum surface temperature shall be assessed. When used in an intrinsically safe circuit within their normal rating and at a maximum ambient temperature of 40 °C, switches, plugs, sockets and terminals will have a maximum surface temperature of less than 85 °C, so they can be allocated a T6 temperature classification for Group II applications and are also suitable for Group I and Group III applications. For other types of simple apparatus the maximum temperature shall be assessed in accordance with 5.6 of this standard.

Where simple apparatus forms part of an apparatus containing other electrical circuits, the whole shall be assessed according to the requirements of this standard.

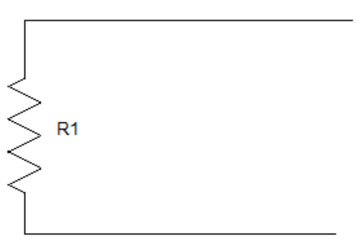
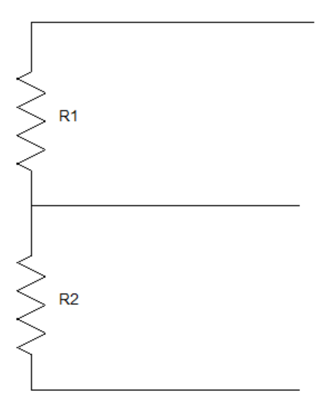
NOTE 1 Sensors which utilize catalytic reaction or other electro-chemical mechanisms are not normally simple apparatus. Specialist advice on their application should be sought.

NOTE 2 It is not a requirement of this standard that the conformity of the manufacturer's specification of the simple apparatus needs to be verified.

All of the TRM Sensors probes meet the first clause in each of the above citations:

> "Passive components, for example switches, junctions boxes, resistors and simple semiconductor devices"

TRM Sensor probes are passive resistor devices. There are no components that increase voltage, nor are there any components that generate energy. There are no added capacitors or inductors to store energy, but the leader cable does add small amounts of capacitance and inductance summarized in the tables below. The circuit for TRM probes follow one of these two schematics:

TRM-DFS-3, TRM-CC, TRM-HX:	TRM-CB, TRM-UST
	

A simple apparatus does not adversely impact a circuit that is considered to be intrinsically safe. But how do we know that a device and circuit used to energize and monitor TRM Sensors probe is intrinsically safe to begin with? The simplest, and most cost effective solution, is to install an agency approved zener safety barrier between the monitoring device (in the control room) and the TRM probe installed in the hazardous area.

For two wire probes (TRM-DFS-3, TRM-CC and TRM-HX) TRM Sensors recommends zener barrier mode MTL 7760ac (manufactured by Measurement Technologies Limited). For three wire probes (TRM-CB and TRM-UST) TRM Sensors recommends MTL 7789+.

Measurement Technologies Limited has obtained and maintains multiple North American and International safety approvals for each of these barriers that assure the hazardous area side of the circuit is intrinsically safe as long as the control room side of the barrier is not exposed to more than 250 Volts and the barrier is installed in accordance with MTL's instructions. Approval certificates are available for MTL 7760ac and MTL 7789+ from the following agencies:

MTL7760AC	EAC	TC RU C-GB.ME92.B.00739	Russia
MTL7760AC	KOSHA	13-AV4BO-0591	Korea S
MTL7760AC	CSA	1345550	North America
MTL7760AC	FM	3010737	USA
MTL7760AC	Baseefa	BAS01ATEX7217	Europe
MTL7760AC	Baseefa	IECExBAS04.0025	International
MTL7760AC	TestSafe	IECExTSA05.0036X	International
MTL7760AC	MTL	MTL13ATEX7700X	Europe
MTL7760AC	MTL	MTL14DOC7700	Europe
MTL7760AC	NCC	NCC 13.2123	Brazil
MTL7760AC	PESO (CCoE)	P305769	India
MTL7760AC	UL	E120058-04NK16349	USA
MTL7760AC	NEPSI	GYJ101297	China
MTL7760AC	PESO (CcoE)	P372043	India
MTL7760AC	NEPSI	GYJ16.1154	China
MTL7760AC	FM	FM16US0708X	USA
MTL7760AC	MSHA	MTL7700_MSHA	USA
MTL7789+	EAC	TC RU C-GB.ME92.B.00739	Russia
MTL7789+	LR	06/00112	International
MTL7789+	CSA	1345550	North America
MTL7789+	FM	3010737	USA
MTL7789+	Baseefa	BAS01ATEX7217	Europe
MTL7789+	Baseefa	IECExBAS04.0025	International
MTL7789+	TestSafe	IECExTSA05.0036X	International
MTL7789+	MTL	MTL13ATEX7700X	Europe
MTL7789+	MTL	MTL14DOC7700	Europe
MTL7789+	NCC	NCC 13.2123	Brazil
MTL7789+	UL	E120058-04NK16349	USA
MTL7789+	PESO (CcoE)	P372043	India
MTL7789+	FM	FM16US0708X	USA

The voltage energizing the TRM probe and the current flowing through the resistor element are typically far below intrinsically safe limits. In the case of TRM Relay Unit Type-CV, the excitation voltage is less than 5 volts and the maximum current is less than 500 micro-amps. The purpose of the zener safety barrier is to assure that even if there is a malfunction in the monitoring device, the instantaneous voltage and current passing into the hazardous area never exceeds the intrinsic safety limits. The barrier functions like a combination of a fuse and voltage clamp. As long as the instantaneous voltage and current stays under the limits imposed by the barrier, then the barrier has a minimal impact on the monitoring operation. However, the barrier imposes limits only on the instantaneous levels of voltage and current. The complete safety analysis has to include the possibility that a small trickle of energy passing through the barrier is used to slowly charge a capacitor or inductor that could discharge quickly somewhere in the hazardous area. This concern leads to the second clause in the NEC and IEC definition of simple apparatus.

NEC and IEC:

b) sources of stored energy consisting of single components in simple circuits with well-defined parameters, for example capacitors or inductors, whose values shall be considered when determining the overall safety of the system;

The internal capacitance of the TRM probes is very low and has been measured as follows including their standard length leader cables:

	TRM-DFS-3 with 2m of leader cable	TRM-CC with 3m of leader cable	TRM-CB with 3m of leader cable	TRM-UST with 10m of leader cable	TRM-HX with 3m of leader cable
Sensor Capacitance (Note 1)	0.4 nF (Note 2)	0 (Note 3)	1.1 nF	1.5 nF	1.1nF
Sensor Inductance (Note 4)	2.36 uH	3.46 uH	3.46 uH	11.8 uH	3.46 uH

Note 1: Capacitance is highest value measured between any two conductors of the leader cable
Note 2: Sensor element removed
Note 3: Both conductors permanently shorted by sensor film
Note 4: Inductance of the sensor body is too low to measure. The reported value is the self-inductance of 22 AWG conductors used in the standard leader cable (2 times the length of the leader cable since a potential inductive circuit would be one conductor outbound and the second conductor inbound).

In a typical installation, the inductance and capacitance of the interconnect cabling used between the probe and the zener barrier (in the control room) has a much larger impact on the total circuit capacitance and inductance than the probe itself.

MTL zener barriers' approval certificates include maximum permissible cable capacitance and inductance.   These are the limits for the two recommended barriers:

	MTL 7760ac	MTL7789+
Maximum Allowable Capacitance	3 uF	0.83 uF
Maximum Allowable Inductance	0.91 mH	16 mH

Maximum Length of Interconnect Cable analysis: TRM Sensors recommends the use of 4 x 22 AWG tray rated jumper cable. (Note that two of the conductors will be unused for TRM-DFS-3, TRM-CC and TRM-HX while one conductor will be unused for TRM-CB and TRM-UST.)   The nominal capacitance for a pair of 22 AWG conductors in a 25 pF per foot.   So, by taking the lower of the two barrier capacitance limits (0.83 uF for the MTL 7789+) and subtracting the highest value of the sensor probes' internal capacitance (1.5 nF for the TYRM-UST) we 0.828 uf of allowable cable capacitance to work with. At 25 pF per foot of 22 AWG pair, this implies a maximum cable length of over 33,000 feet or about 10 km.   Using the same analysis for inductance we start with the 'worst case' 0.91 mH limit for the 7760ac barrier, subtract the 'worst case' sensor internal inductance of 11.8 uH (for the TRM-UST probe) leaving 898 uH for the cable. At 0.18 uH per foot this implies a limit of 4888 ft for the permitted length of 22 AWG conductor. Since the cable includes both an outbound and inbound length of 22 AWG conductor the maximum cable length is 2444 ft or about 745m.   Combining these two analyses, the lowest connect cable length limitation occurs with the TRM-UST and an MTL 7760ac barrier.   The limit for this combination is 745m. To provide a reasonable safety margin for cable variations, TRM Sensors recommends that jumper cable lengths between probe and zener safety barrier (in the control room) be limited to 500m.

T-Class Analysis: The IEC standard (but not the NEC Code) recommend that simple apparatus operating in explosive atmospheres also require a maximum temperature analysis:

- when simple apparatus is located in the explosive atmosphere, the maximum surface temperature shall be assessed. When used in an intrinsically safe circuit within their normal rating and at a maximum ambient temperature of 40 °C, switches, plugs, sockets and terminals will have a maximum surface temperature of less than 85 °C, so they can be allocated a T6 temperature classification for Group II applications and are also suitable for Group I and Group III applications. For other types of simple apparatus the maximum temperature shall be assessed in accordance with 5.6 of this standard.

For TRM probes the value of the sensor element resistors (R1 in the above schematics) changes as a function of the resistivity of the sensor material. A lower limit for TRM-DFS-3 is about 30 ohms in the clean and dry state but R1 can be 100 to 500 ohms after an hydrocarbon and during partial reset. The largest possible power dissipation in the sensor occurs when the zener barrier is passing its maximum voltage and the resistance of the sensor probe is equal to the internal resistance of the barrier.   For the MTL 7760ac each channel has a nominal 50 ohm resistor or 100 ohms for the total barrier internal resistance. If the sensor element is also 100 ohms the conditions for maximum power dissipation in the sensor element occur.   Assuming the barrier is passing its maximum permissible voltage (10 volts for the MTL 7760ac) then 5 volts are dropped inside the barrier and 5 volts are dropped across the 100 ohm sensor element.   Power dissipation in the sensor element is V^2/R or 25/100 or 0.25W.

A similar analysis for the TRM-UST and the MTL 7789+ yields a maximum power dissipation at the sensor element of 0. 65 W if the sensor element is 300 ohms and the applied voltage is at the maximum 28 V permitted to pass through the barrier.

TRM-DFS-3 and TRM-UST share the same sensor element. The hydrocarbon sensitive carbon film is deposited on a thin ribbon cable substrate that is not normally used to dissipate heat. In actual use the substrate is either in contact with a concrete floor surface or drip pan (TRM-DFS-3) or is surrounded by a think wall brass tube (TRM-UST) and either of those structures would act as a heat sink. But for safety analysis, the worst case scenario is to suspend the sensor element in free air (without any heat sink). Sufficient voltage is then applied to the sensor element to dissipate the desired power either 0.5W or 0.65W as suggested by the matched power analysis above.

Because the ribbon cable substrate is not typically called upon to dissipate heat, several experimental runs were conducted to measure the heat rise. The sensor element was suspended in free air, a constant voltage was applied (calculated to generate 0.65W given the initial measured sensor element resistance) and the temperature rise at the element was observed every 15 seconds for a period of five minutes. In all runs the temperature stabilized after about 3 minute. The maximum temperature increase observed was 22.4˚C. <u>Allowing for experimental variables an estimate of maximum expected temperature increase at the maximum power transfer through either the MTL 7760ac or MTL 7789+ is taken to be 30˚C</u>

The TRM-CB, TRM-CC and TRM-HX have higher initial starting resistance and are unlikely to reach a resistance value that would allow the maximum power transferred through the barrier, 0.65W, to occur. Additionally, the physical structure of the TRM-CB, TRM-CC and TRM-HX include a large stainless steel core rod that would dissipate heat much more effectively than the thin ribbon cable used in the TRM-DFS-3 and the TRM-UST. Therefore it is safe to assume that worst case temperature increase for the three larger sensor probes is less than the 22.4˚C observed in the experimental data.

Based on the experimental data, and using Ta of 40C, the maximum surface temperature of any of the sensors at the barrier limit points will be 70C or less<u>. Therefore the TRM Sensors models TRM-DFS-3, TRM-UST, TRM-CB, TRM-CC and TRM-HX when installed in conjunction with either an MTL 7760ac or an MTL 7789+ qualify for temperature code T-6</u>

It should be noted that the above analysis is a worst case scenario, with no heat sink, the resistance of the sensor at the value that maximizes the power transfer through the barrier and failures in the monitoring equipment that allow the excitation voltage to reach, but not exceed the limits of the barrier. In more realistic scenarios where the sensor element is in contact with a concrete floor or surrounded by a larger metallic component; where the resistance of the sensor element is not at the value where the maximum power is transferred; and when the monitoring device is operating at design values, then the power dissipated by the sensor is much lower that what was experimentally analyzed and the temperature rise is negligible.

Conclusion:

- TRM Sensors models TRM-DFS-3, TRM-UST, TRM-CC, TRM-CB and TRM-HX are 'simple apparatus' per the definitions of National Electrical Code, NFPA 70 – 2014 edition, article 504 and IEC 60079-11:2011 (and EN 60079-11:2012) clause 8.7.

- TRM Sensors recommends the following zener safety barriers:
    - MTL 7760ac for TRM-DFS-3, TRM-CC and TRM-HX
    - MTL 7789+ for TRM-CB and TRM-HX

- As simple apparatus, the TRM Sensors probes can be safely installed in hazardous areas when the probes are connected to the control monitoring equipment via recommended zener safety barriers. The approvals associated with the selected zener safety barriers provide for the inclusion of simple apparatus in the hazardous area.

- When installed with the recommended barriers, the capacitance and inductance of the jumper cable used to connect the probe to the barrier dominates the energy storage calculations. When the recommended 4 x 22AWG jumper cable is used, the maximum length of jumper cable should be 500m or less.

- In accordance with the IEC regulation, a worst case heat rise was experimentally determined using the maximum theoretical power that could pass through the recommended zener barriers. The maximum observed temperature increase was less than 30˚C. Assuming a T_a of 40˚C and adding the 30˚C maximum observed temperature increase, the maximum surface expected surface temperature would be 70˚C and this qualifies all TRM Sensor probes as Temperature Class T-6