

Drive-cycle Requirement Specifications

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Abstract –

The aim of this report is to provide an electronics control system to be used on an F1 sidecar for a customer to use in attempts to break the current FIM land speed record. The main focus was on specifying and exploring a traction control system that could work with a MoTeC M1 series ECU. Various sensor types and equipment specifications have been explored and reviewed, leading to a final recommendation that has been given to the customer for their use.

1. INTRODUCTION

Previous work, [1] where a drive cycle for an F1 sidecar was identified and specified for an attempt to break the current FIM [2] electric land speed record of 110.389mph on the Bonneville salt flats [3] has provided the basis of the work to be conducted within this report.

Analysis of [1] found that there were some flaws regarding battery specification and cell size, along with some issues regarding ohmic losses between battery connections. It was decided that these flaws had a negative impact on results, along with the overall possibility of breaking the record.

Based on these findings, a thorough consultation was conducted with the customer, where it was agreed that the project would be taken in a slightly different direction to improve their chance of achieving their goal and breaking the record in future.

It was decided with the customer that analysis of the performance of the existing Internal Combustion Engine (ICE) and particularly the ability to retain maximum grip using a Traction Control (TC) system would be completed. It was also confirmed that the sidecar was equipped with a MoTeC M1 series [4]

Electronic Control Unit (ECU) which allows for greater control on systems and strategies when compared with standard or kit electronics packages.

This work would form the basis of knowledge needed by the customer leading to control work surrounding the Sevcon [5] Electric Vehicle (EV) record attempts in future.



Figure 1 – MoTeC M1 series ECU. [6]

Throughout this report, TC systems will be explored in detail and relevant suggestions will be made as to decisions that the customer should make regarding hardware and strategy. It was important to consider customer requirements throughout the process as certain aspects of the system would differ in relation to the nature of which it will be operating at on the salt flat, which can differ significantly to a normal asphalt surface/race circuit.

2. Literature Review

So that the customer was equipped with a machine that could maintain maximum grip and acceleration throughout a run on the salt flat and ultimately break the record, it was important to understand TC systems in depth, especially through the MoTeC M1 system which was installed on the sidecar.

2.1 Traction Control Overview

Motorcycles are subject to significant load transfer when accelerating and braking. During these phases, load is transferred either to the front of the machine when braking or to the rear when accelerating.

During acceleration, longitudinal force is generated between the salt flat surface in this example, and the contact patch of the driving tyre on the sidecar. This longitudinal force causes the front of the contact patch to compress and creates adhesion between the tyre and salt flat surface which creates forward stress. As the driving wheel rotates, slip occurs when the tyre slides on the salt flat surface. [7]

Slip is often represented as a ratio in percent and is obtained from wheel speed measurements.

$$\text{Slip ratio \%} = \left(\frac{\text{Re Wheel Speed}}{\text{Fr Wheel Speed}} - 1 \right) \times 100$$

Equation 1 – Slip ratio equation. [8]

TC systems work based on a slip ratio target, which is defined in the MoTeC M1 Tune software in this case and represents the maximum desired slip. It is worth noting that this value can change between surfaces and is dependent on rider preference.

When wheel slip exceeds the target value, the ECU is then able to introduce TC through several methods to bring the slip back into a manageable amount that the rider can still maintain high throttle demand/speed at.

TC is deployed by reducing the amount of torque that the engine is able to deliver. This can be done either through cutting the amount of fuel that is delivered into the cylinders of the engine, or by cutting ignition of fuel that is already in a cylinder. Both methods can be used either individually or combined. They both offer advantages and disadvantages.

To utilize a TC system, the following sensors must be fitted to the motorcycle to analyse the data generated which can be used for TC strategies:

- Throttle position
- Engine speed
- Gear position
- Rear suspension (optional)

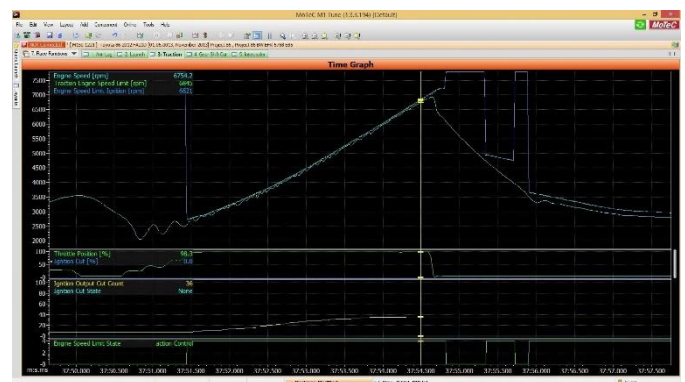


Figure 2 – Example data showing TC being utilized through a MoTeC M1 ECU. [9]

2.2 MoTeC M1 Traction Control Operation

The MoTeC M1 electronics package calculates its TC strategy based on a slip target, represented in % and performs a Proportional Integral Derivative (PID), closed loop control of fuel and/or ignition cut depending on the set up defined by the engineer. [10]

As with all TC systems, the MoTeC M1 system will aim to maintain slip within the defined slip target and introduce torque reduction when slip exceeds the target value.

PID controls are instruments used widely across the automotive and motorcycle industry and use a control loop feedback mechanism to control their variables. [11]

Once slip target (%) values have been defined within the MoTeC M1 package, the system converts them to a value known as the Traction Engine Speed Limit. This is due to the accuracy level of engine speed and RPM readings from the system. It then uses the wheel speed values which are taken from Hall Effect [12] wheel speed sensors and reverse engineers the value. From this the MoTeC system knows for a given wheel speed

what the correlating slip target is depending on the target set by the engineer. [10] There is a simple example of how this works shown below.

	Engineer Defined Slip Target	10%
	Driven Wheel Speed (kmh)	100
	10% of Rear Wheel Speed (kmh)	10
∴	Driven Wheel Speed Inc. Slip Target (kmh)	110
	Assuming that the undriven wheels have remained at 100kmh.	

Figure 3 – Simplified example of MoTeC M1 TC calculation.

Using all of the previous information, MoTeC M1 is then able to convert the values depending on wheel circumference, final drive ratios, and current gear and calculate what the value would represent in terms of RPM.

This correlated RPM value is then automatically applied by MoTeC M1 to be the Traction Engine Speed Limit [10]. Due to this being within a closed loop system, MoTeC is able to constantly update this value depending on the previous status of parameters mentioned. This allows the system to maintain greatly refined control on its TC strategy, as opposed to a blanket map that may be applied with more simple systems.

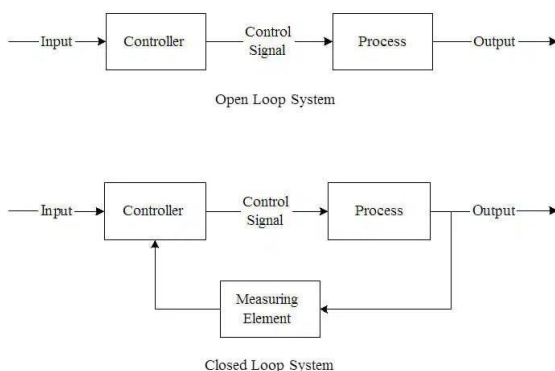


Figure 4 – Open vs closed loop system operation [13].

As mentioned, it is common to use ignition or fuel cutting, or a combination of both. Generally, it is desired to focus on using fuel cutting wherever possible, and only use ignition cutting if it is absolutely necessary. Ignition cutting can cause problems within the engine if used excessively, (i.e., when ignition cut is near to 100%). Fuel cutting is a less aggressive method of introducing TC whereas ignition cutting results in a lot of unburnt air/fuel being sent through

the exhaust system which can result in backfiring and could also lead to engine problems [10].

Rider preference also has an impact on the TC strategy, as some riders prefer a harsh, more aggressive TC whereas some prefer a more subtle intrusion, often found through using only fuel cutting.

Traction engine speed limit fuel margin is the value that the MoTeC M1 package defines the method in which TC will be deployed. If the Traction engine speed limit fuel margin value is positive (above 0), then the system will begin with an ignition cut, and if the value is negative, then it will begin with a fuel cut strategy [10].

For example, if the traction engine speed limit fuel margin value is set to -500rpm, then the strategy will begin with an initial fuel cutting strategy and ignition cutting will not begin until 500rpm above the defined fuel cut starting limit. This value should be high enough that it is out of reach for introducing any ignition cutting if desired.

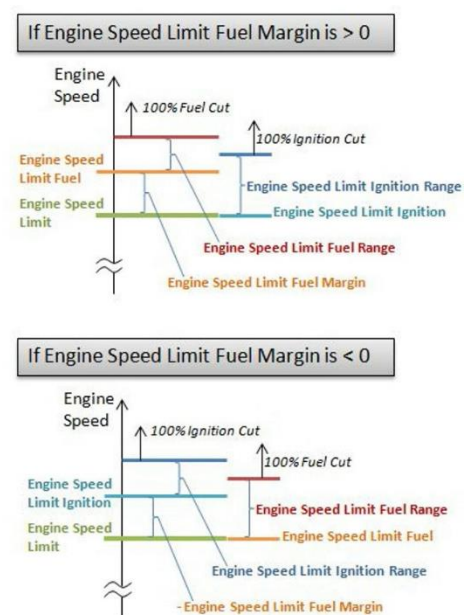


Figure 5 – Traction engine speed limit fuel margin explanation from MoTeC M1 package. [10]

2.3 Sidecar Variables and Operating Conditions

As mentioned previous, there are some pieces of information that are crucial to the overall performance of not only the TC system, but the sidecar in general when performing on the Bonneville salt flat.

Tyre choice is critical, as it should be a tyre that is able to withstand the demands that the rider is giving it, while also always achieving the best possible grip. Some research was conducted into typical sidecar tyres that are used specifically in racing use. Research showed that across the world, Avon Tyres [14] were used in most/if not all domestic championships and road racing. After consultation of the FIM land speed record regulations [15], there were no limitations on tyre choice, providing that the tyre had minimum of 2.5mm tread depth.

This information was presented to the customer, and it was confirmed that Avon slick tyres would be used. Information regarding this tyre choice can be found below.

F1 Sidecar Avon Slick Tyres	
Compound	A53 (11851)
Section Width	230
Aspect Ratio	55
Rim Diameter	13

Figure 6 – Avon F1 Sidecar slick tyre specifications. [16]

Some consideration was made regarding tyre compound, as the surface at Bonneville is salt which can be particularly un-predictable. It was decided along with the customer that a medium compound tyre would be used, as shown in figure 6. The main reason for this is so that the tyre can cope with high speeds on a salt surface for the duration of the run. A softer compound tyre could have been chosen, which may have been better in terms of performance, but lack in reliability. A medium compound tyre can offer the best compromise between performance and durability.

2.4 Constants

Constants		
	Value	Unit
Gravity	9.81	ms ⁻²
Rolling Resistance Coefficient	0.45	μ
Drag Resistance Coefficient	0.41	μ
Frontal Area	0.5085	m ²
Ambient Temperature	298	K
Ambient Air Density	1.1834	kgm ⁻³

Figure 7 – Constants table relevant to the sidecar and Bonneville salt flats.

The previous figure includes some information on the sidecar frontal area, along with air density and temperature information. Temperature has been generally assumed to be 298K (25°C), of course this would change depending on when the runs take place. As would air density.

3. Hardware Recommendations

Recommendations on which hardware, specifically sensor types and versions were to be made to the customer, so that a designated wiring loom could be manufactured for the sidecar.

As previously mentioned, the sidecar was fitted with a MoTeC M1 series ECU, which can control and monitor all relevant engine parameters and control strategies adequately.

Previously within this report, there is a list that contains some relevant sensors that the sidecar should be fitted with so that a suitable TC system can be used.

To employ fuel and ignition cutting, there are some more sensors that it has been recommended to the customer to be fitted:

- Intake Air temperature Sensor (IATS)
- Intake Air Pressure Sensor (IAPS)/Manifold Air Pressure Sensor (MAPS)*]
- Engine oil temperature sensor
- O2 sensor

*- If the OEM throttle body isn't already fitted with one.

Information regarding the above sensor requirement was found at [17].

The following discussion within this report will outline potential sensors that could be used and evaluate their feasibility for use on the sidecar for use on the Bonneville salt flat.

All sensor options were compared initially based on their cost, availability, fit for purposeness, ease of integration, and operating life. It was important to consider component availability as the Covid-19 pandemic inflicted a long-lasting effect on electronic component production and supply. It was deemed as unsuitable to recommend a component to the customer that was not readily available.

Consideration of compatibility and ISO standards was also considered due to the conditions that the recommended components would be used in when on the salt flat.

3.1 Throttle Position Sensor

A throttle position sensor would be mounted at the throttle on the sidecar handlebar and are rotary potentiometers that work based on an angular reading.

There were four different brands of throttle sensor that were analysed, all of them a 'D-drive' which represents a small metallic shaft in the shape of a D which when rotated, would provide a reading to the MoTeC M1 series ECU.

Throttle Position (Rotary Potentiometer) Sensor Decision Matrix					Scale	
Version	MoTeC	KA Sensors	4QD Sensors	Alps Alpine	1	Worst
Cost	3	4	2	5	2	
Availability	4	4	4	3	3	
Fit for Purposeness	5	4	4	3	4	
Ease of Integration	5	5	3	3	5	Best
Operating Life	4	4	5	2		
Total	21	21	18	16		

Figure 8 – Throttle position (rotary potentiometer) sensor decision matrix.

Sensors analysed were:

- MoTeC [18]
- KA Sensors [19]
- 4QD Sensors [20]
- Alps Alpine (RS Online) [21]

As figure 8 shows, both the MoTeC and KA sensors brand rotary position sensors were deemed suitable for use. Both sensors are of relative cost and would be suitable for use within the MoTeC M1 electronics system.

The KA KH Series KH21&22 sensor was explored extensively due to extensive mechanical life (25 million cycles), it was manufactured within an aluminium housing, meaning it could withstand vibration well. The sensor has an Ingress Protection (IP) rating of IP67, which based on the worldwide IP rating system, it would be 'fully protected against dust and other particulates' and was fully protected 'against full immersion for up to 30 minutes at depths between 15cm and 1 meter' which suggests that the sensor would be a perfect solution [22].

IP (INGRESS PROTECTION) RATING GUIDE	
SOLIDS LEVEL OF INGRESS PROTECTION	WATER LEVEL OF INGRESS PROTECTION
1 Protected against a solid object greater than 50mm (such as a hand) (50N of force).	1 Protected against vertically falling drops of water for 10 minutes at rate of 1mm/min.
2 Protected against a solid object greater than 12.5mm (such as a finger) (10N of force).	2 Protected against diagonally falling (up to 15°) drops of water for 10 minutes at rate of 3mm/min.
3 Protected against a solid object greater than 2.5mm (such as a screwdriver) (5N of force).	3 Protected against diagonally falling (up to 60°) sprays of water for 5 minutes at 0.7 LPM at 80-100 kPa.
4 Protected against a solid object greater than 1mm (such as a wire) (5N of force).	4 Protected against water splashed from all directions for 5 minutes at 10 LPM at 80-100 kPa.
5 Dust protected. Limited ingress of dust permitted. Will not interfere with operation of equipment.	5 Protected against a 6.3mm water nozzle for 3 minutes at 12.5 LPM at 30 kPa at a distance of 3 meters.
6 Dust tight. No ingress of dust.	6 Protected against a 12.5mm water nozzle for 3 minutes at 100 LPM at 100 kPa at a distance of 3 meters.
	7 Protected against 30 minute submersion at a depth of 1 meter.
	8 Protected against continuous submersion for long periods at a depth of 3 meters.
	9K Protected against powerful, high temperature water jets.

Figure 9 – Ingress Protection (IP) rating guide [23]

3.2 Wheel/Crankshaft Speed Sensor

Hall effect sensors could be used to acquire both wheel and crankshaft speed. For that reason, options for both have been included within one singular decision matrix.

Speed (Hall Effect) Sensor Decision Matrix					
Version	MoTeC	KA Sensors	EFI Sensors	Scale	
Cost	2	4	2	1	Worst
Availability	4	4	4	2	
Fit for Purposeness	5	5	4	3	
Ease of Integration	5	5	3	4	
Operating Life	4	4	4	5	
Total	20	22	17		Best

Figure 10 – Wheel/Crankshaft speed sensor decision matrix.

There were sensors by three different manufacturers that were considered. It is worth remembering that these sensors could be used to acquire both wheel and crankshaft speeds, so it was deemed unnecessary to have another decision matrix.

Sensors manufactured/supplied by the following companies were considered:

- MoTeC [24]
- KA Sensors [25]
- EFI Sensors [26]

Figure 10 shows that the KA manufactured sensor was the best in terms of score. When evaluating the provided data sheet for the KA sensors SPI Series Speed Sensor, it showed that the sensor had been tested for use in up to 150°C, which would be more than suitable for use on the sidecar. The sensor has a measurement frequency of 8KHz, which would be more than suitable for feeding enough information to the MoTeC M1 electronics package. As with the recommended throttle position sensor, this KA SPI speed sensor came with an IP rating of IP67 and was constructed within an anodized aluminium housing, which ensured that the component would not fail due to dust ingress and would be able to withstand water, even though this would be unlikely in the context of the Bonneville salt flat [25].

As mentioned at the beginning of this sub-section, this recommended sensor could also be used to measure crankshaft speed, which of course is a bonus, meaning that the customer would not have to purchase multiple of the same sensor type from multiple manufacturers.

3.3 Temperature Sensors

Two sensors would be required for measuring temperature on the sidecar. One sensor would be required to measure intake air temperature, and the other to measure engine oil temperature. As with previous sensors discussed, there were multiple options to consider.

Sensors considered within this sub-section were manufactured/supplied by:

- MoTeC (Air) [27]
- KA Sensors (Air) [28]
- KA Sensors (Oil) [29]
- Continental Aftermarket (Oil) [30]

Temperature Sensor Decision Matrix					Scale	
Version	MoTeC	KA Sensors (Air)	KA Sensors (Oil)	Continental Aftermarket (Oil)	1	Worst
Cost	3	3	3	4	2	
Availability	4	3	3	4	3	
Fit for Purposeness	5	3	3	3	4	
Ease of Integration	5	5	5	4	5	Best
Operating Life	4	5	4	2		
Total	21	19	18	17		

Figure 11 – Oil/air temperature sensor decision matrix.

Based on results shown in figure 11, A MoTeC supplied Delco air temperature sensor was deemed as suitable. Since this sensor was supplied from the MoTeC website, there would be no issues with integrating this sensor into the overall electronics system. The sensor features an operating temperature of 0 to 110°C [27], which is a range far wider than the expected range of air temperatures that the sidecar may experience while running on the salt flat. The sensor would be mounted within the airbox and therefore after the air filter. This therefore meant that the sensor would not be subjective to any dust or water, meaning the IP rating of this sensor was not of significant importance.

In terms of a suitable oil temperature sensor, it was decided that the KA Sensors NTC1 fluid temperature sensor would be the best recommendation to the customer. The sensor has an operating temperature of -30 to 150°C, and the provided datasheet claims that the sensor has an accuracy of $\pm 1^\circ\text{C}$, which was of high enough accuracy for use within this application [29].

The NTC1 fluid temperature sensor was also IP67 rated, like other sensors that were recommended, this sensor would easily be able to withstand any possible operating conditions that it may be subjected to while fitted to the sidecar [29].

3.4 Connector Type

Some consideration was also given to the type of connector, often referred to as 'plug' that would be used on the wiring harness for the MoTeC M1 electronics package.

There are two main types of connectors that were considered, these were DTM [31], and Deutsch Autosport [32] connectors.

Both connector types could have been recommended to the customer for use on this project, however Deutsch Autosport connectors are felt to be the best option due to their development for use in extreme conditions and their tendency to be highly resistant to vibration. Vibration can cause vast amounts of issues with connectors and cause inconsistent connection, which could lead to an inconsistent reading from the sensor.

From the Deutsch Autosport connector datasheet PDF, it was observed that these connectors were available in a wide range of configurations and versions. The sensors have been developed to a point where they are recognized as the highest available standard connector on the market. Some advantages of the Deutsch Autosport connector are as follows [32]:

- Compact design
- Interfacial & wire sealing
- Positive locking coupling mechanism
- Surface finishing options are available.

One main factor that can be distinguished between using DTM and Deutsch Autosport connectors would be cost. Based on the customer requirement, they would be prepared to facilitate the use of Deutsch Autosport connectors to ensure that they receive the

best possible equipment to enhance their chance of achieving their goals.

Connector Type Decision Matrix				
Version	DTM	Deutsch Automotive	Scale	
Cost	4	2	1	Worst
Availability	4	4	2	
Fit for Purposeness	4	5	3	
Ease of Integration	5	5	4	
Operating Life	3	5	5	Best
Total	20	21		

Figure 12 – Connector type decision matrix.

4. Final System Recommendations

Based on all the information that has been produced and discussed within this report, a final recommendation has been made to the customer as to a specification of sensors and equipment that it is felt they should use on their sidecar for use on the Bonneville salt flat.

As already confirmed, the sidecar was fitted with a MoTeC M1 series ECU, so to accompany this it was necessary to define and recommend all sensors that would be needed to work with the system.

Based on the research conducted within this report, it is recommended that the customer should equip the following equipment and sensors to the sidecar:

- Avon A53 (11851) slick racing tyres



Figure 13 – Avon A53 (11851) slick racing tyre [33]

- KA Sensors KH Series KH21&22 non-contact rotary position sensor



Figure 14 – KA Sensors KH21/22 rotary position sensor [19]

- KA SPI speed sensor



Figure 15 – KA SPI speed sensor [25]

- MoTeC/Delco air temperature sensor



Figure 16 – MoTeC/Delco air temperature sensor [27]

- KA Sensors NTC1 fluid temperature sensor



Figure 17 – KA NTC1 fluid temperature sensor [29]

- Deutsch Autosport connectors



Figure 18 – Deutsch automotive connectors [34]

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