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## School of Engineering

What impact do electronic control systems and strategies have on high-level racing motorcycles and how can they be optimised?

Research Proposal

Research Methods & Professional Development

ACFA7004

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# Nomenclature

- Brake Horsepower (BHP)
- Traction Control (TC)
- Anti-lock Braking (ABS)
- Engine Brake (EB)
- Anti-Wheelie (AW)
- Fuel Injection (FI)
- Launch Control (LC)
- Ride by Wire (RBW)
- British Superbikes (BSB)
- Electronic Control Unit (ECU)
- Kawasaki Quick Shifter (KQS)
- Bosch Internal Measurement Unit (IMU)
- Kawasaki Cornering Management Function (KCMF)
- Sport-Kawasaki Traction Control (S-KTRC)
- Kawasaki Launch Control Mode (KLCM)
- Kawasaki Intelligent Anti-Lock Braking System (KIBS)
- Inertial Measurement Unit (IMU)
- Yamaha Chip Controlled Throttle (YCC-T)
- Central Processing Unit (CPU)

# 1 Introduction

Major motorcycle manufacturers are producing motorcycles with increased Brake Horsepower (BHP) year on year, and with this additional power comes more advanced electronic control systems, implemented to allow the rider to utilise maximum power and performance in any given situation. With such electronic control systems becoming increasingly common, newly developed configurations and system architectures are greatly improving the level at which racing motorcycles can compete. (“Motorcycle Dynamics | VI-grade,” n.d.)

Motorcycle electronic control systems were first seen in the form of Anti-lock Braking (ABS) and Traction Control (TC) systems in 1988 and 1992 respectively. These systems provided poor performance and it wasn’t until racing teams proved the importance of TC systems that they were more widely introduced in the late 2000’s. (*Modelling, Simulation and Control of Two-Wheeled Vehicles*, n.d.)

ABS systems commonly aren’t permitted or aren’t used in most racing contexts. The Federation Internationale de Motocyclisme (FIM), the organising body of MotoGP banned the use of ABS, stating in (“RÈGLEMENTS DU CHAMPIONNAT DU MONDE FIM DES GRANDS PRIX FIM WORLD CHAMPIONSHIP GRAND PRIX REGULATIONS 2022,” n.d.) that ‘Braking inputs must be powered and controlled solely by the rider’s manual inputs.’ Therefore, ABS will not be extensively explored within this body of work.

Many electronic control systems have been developed in racing scenarios which have then progressed into road-going factory manufactured sports motorcycles. Systems to be explored within this body of work include:

- Traction Control (TC)
- Engine Brake (EB)
- Anti-Lift or Anti-Wheelie (AW)
- Fuel Injection (FI)
- Launch Control (LC)
- Ride by Wire (RBW)

Substantial amounts of research and information documented within this body of work was provided by GR Motosport (“GR Motosport | British Superbike Team,” n.d.), a British Superbike (BSB) team which the author has an affiliation with. Significant amounts of research have therefore been conducted relevant to a 2021- present Kawasaki ZX10-RR Ninja motorcycle due to it being the same machine used by the team in BSB and due to the extent of technical information and datasets available to the author. Suggestions were made by the team regarding specific areas which they felt could be improved or developed regarding electronic control system strategies used in the BSB championship to further enhance overall performance of the motorcycle.

## 1.1 Kawasaki ZX10-RR Mechanical Specifications



**Figure 1** - Kawasaki Ninja ZX10RR. ("2021 Kawasaki ZX-10RR Ninja," n.d.)



**Figure 2** - GR Motosport Kawasaki ZX10-RR BSB bike of 2022. ("Team-LKQ-Euro-Car-Parts-Kawasaki," n.d.)

Table 1 below shows specifications for a Kawasaki ZX10-RR Ninja, as shown above.

|                    |                                                                                               |
|--------------------|-----------------------------------------------------------------------------------------------|
| Engine Type:       | 4-stroke, transverse four cylinder, DOHC, 4 valves per cylinder                               |
| Engine Capacity:   | 998 cc                                                                                        |
| Bore:              | 76.0 mm                                                                                       |
| Stroke:            | 55.0 mm                                                                                       |
| Compression Ratio: | 13.0:1                                                                                        |
| Induction:         | DFI with 47 mm Mikuni throttle bodies (4) with oval sub-throttles, two injectors per cylinder |
| Ignition:          | TCBI with digital advance and Sport-Kawasaki Traction Control (S-KTRC)                        |

## 1.2 Kawasaki ZX10-RR Electronic Specifications

Kawasaki have worked continuously to develop new and existing electronic control systems for their motorcycle. The 2021- present iteration of their ZX10-RR Ninja sports bike is equipped with the following electronic control systems as standard:

- Kawasaki Quick Shifter (KQS)
- Bosch Internal Measurement Unit (IMU)
- Kawasaki Cornering Management Function (KCMF)
- Sport-Kawasaki Traction Control (S-KTRC)
- Kawasaki Launch Control Mode (KLCM)
- Kawasaki Intelligent Anti-Lock Braking System (KIBS)
- Kawasaki Engine Brake Control
- Power Modes

("2021 Kawasaki ZX-10RR Ninja," n.d.)

These items have been listed for contextual purposes to highlight the level of electronic control systems modern sports motorcycles are equipped. Further within this proposal, emphasis will be on systems operating in the same manor and achieving the same results, however implemented in slightly different ways and manufactured by alternative organisations like MoTeC, for example.

The reason for this difference in emphasis is due to the BSB motorcycle shown in figure 1 being equipped with a MoTeC M170 Electronic Control Unit (ECU) (M170 ECU, 2020) which is compulsory for all motorcycles racing in the superbike class of BSB championship. This ECU controls these systems in slightly different ways to standard and offers a wider, more refined scope of adjustment.



*Figure 3 - MoTeC M170 ECU. (M170 ECU, 2020)*

## 2 Literature Review

Literature papers regarding electronic control systems on four-wheeled vehicles are widely available. Additionally, there are papers that explore electronic control systems on motorcycles in general, in which some of the contents are applicable to racing motorcycles. There are few papers that have been published with the sole focus being on racing motorcycle electronic control systems and strategies.

To gain an appropriate understanding of motorcycle electronic control systems and strategies, it was necessary to consult published literature containing research developing electronic control systems on road-going motorcycles. From this it would then be possible to narrow the scope of this proposal to a more racing based context.

### 2.1 Traction Control

TC systems are critical to achieving maximum performance. TC is often deployed under acceleration while exiting a corner. Newton's second law, which states that 'The resultant force acting on an object is proportional to the rate of change of momentum  $p=mv$  of the object'. ("Newton's Second Law — Isaac Physics," n.d.). In this scenario, longitudinal force is generated between the asphalt surface and contact patch of the rear tyre under acceleration. This force causes the front of the tyre contact patch to compress under driving torque. This newly generated force creates adhesion between the tyre and asphalt surface which creates forward stress, as the rear wheel rotates, this

stress is then reversed and the tyre reverts to its original shape and radius. During this phase, slip occurs when the tyre slides on the asphalt surface (Jörge Segers, 2004)

In 2011, Kawasaki released their first iteration of S-KTRC which allows for maximum acceleration during corner exit phases of riding. The system monitors front and rear wheel speed (slip), engine RPM, throttle position, and acceleration. (Masuda and Matsuda, 2011) , (“Engine management,” n.d.).

Slip is defined as ‘The difference in rotation between the front and rear wheels.’ (Michele Trapani et al., 2021). It is often represented via percentage however it can also be expressed as a ratio, known as ‘Slip Ratio’. Slip is the most vital parameter to be monitored by TC systems. When the slip value exceeds a ‘predetermined comparatively larger value’ defined in the ECU, TC will then be introduced to reduce the level of slip to a value the tyre can deal with. (Masuda and Matsuda, 2011).

Older TC systems like Kawasaki S-KTRC described above only take certain parameters into account. Modern, more advanced systems utilise lean angle, otherwise known as bank angle, to accurately determine the amount of force that can be delivered through the rear wheel without excessive slip.(Michele Trapani et al., 2021).

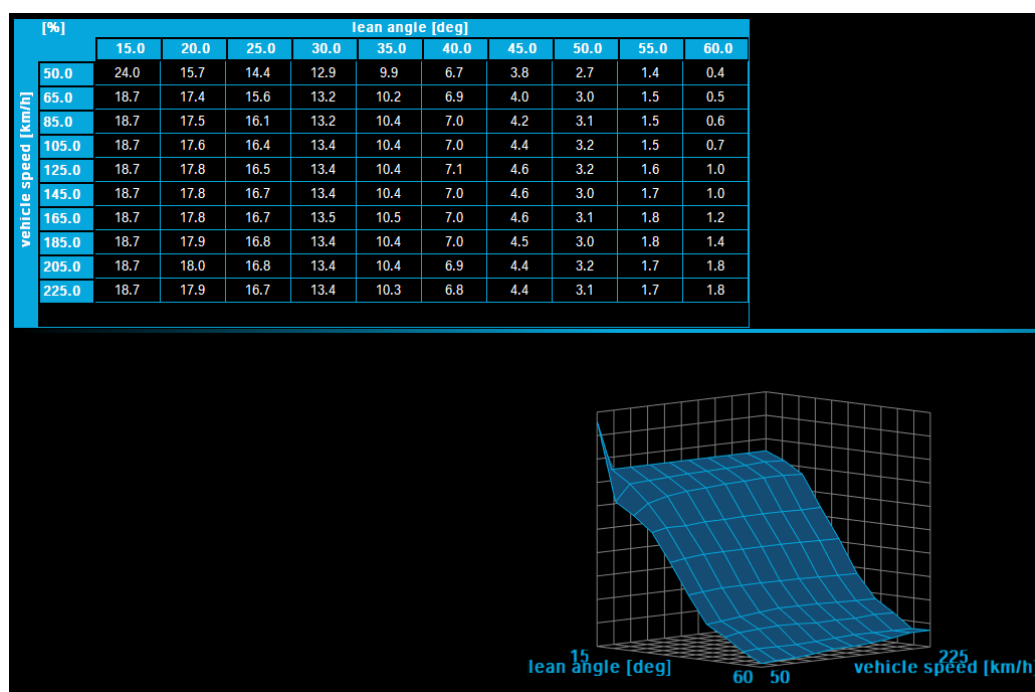


**Figure 4** - BMW M Race Calibration 2019 TC strategy. (“BMW M Race Calibration 2019,” n.d.)

Figure 4 is a brilliant example of BMW’s TC strategy which accounts for lean angle and vehicle speed. The software allows for a TC map for each of the 6 gears. Values occupying cells are the amount of permitted slip in % for each vehicle speed and lean angle value.

Accounting for lean angle in TC systems is beneficial due to significant change in tyre circumference when the motorcycle is subject to lean. This change in circumference alters the amount of slip permissible due to grip levels of the tyre at lean. (“BMW M Race Calibration 2019,” n.d.; Michele Trapani et al., 2021).

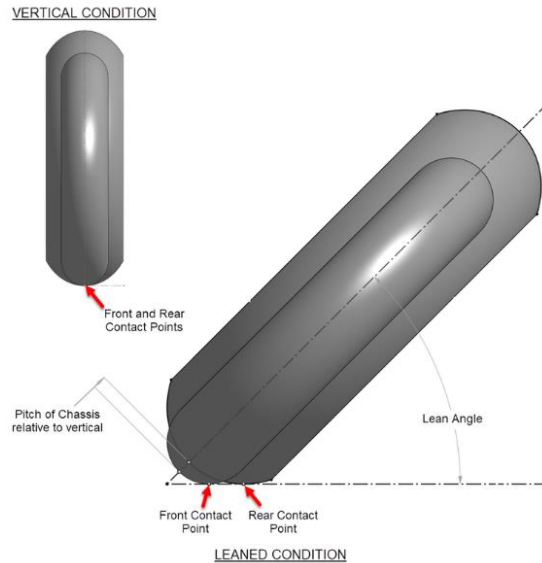


**Figure 5 - Effect of lean angle on tyre contact patch.**  
 ("EFFECTS OF TIRE PROFILE WITH LEAN ANGLE -  
 MotoSPEC CHASSIS PROGRAM," n.d.)

## 2.2 Engine Brake

As explained, TC systems allow the motorcycle to accelerate quickly and aggressively. To slow the motorcycle down from these high speeds, high amounts of braking force are needed. This is where EB systems come in. EB systems use inputs from electronic sensors and calculations via the motorcycle ECU, and IMU to control the amount of braking effort that is contributed by the engine. The contribution of EB is paired with the effort from the hydraulic braking system to help slow the motorcycle. In racing contexts, it is critical that optimum braking is performed to achieve a fast lap time.

EB systems work by altering throttle butterfly position. When a rider closes the throttle, traditionally, the throttle butterfly would completely close. This gives the engine very strong engine brake and reduces cylinder pressure due to no more fuel/air being added to the cylinder. (Dirty Garage Guy, 2017). EB systems are also managed by starving cylinders of fuel, therefore stopping combustion, and slowing the engine speed ("How MotoGP engine-braking control works - Motor Sport Magazine," n.d.).

Figure 6 below shows excellently how EB systems are deployed in a MotoGP race. The figure is taken from a data analysis software from Circuito de Jerez ("the circuit layout - Circuito de Jerez - web oficial," n.d.), on the approach to Sito Pons corner, which is turn 5. It shows throttle closing on approach, and the moment that the rider applies brake and shifts down into third gear. These preceding events puts the engine into engine brake mode. ("How MotoGP engine-braking control works - Motor Sport Magazine," n.d.).

Advanced electronics systems such as the MoTeC system described within this report provide a high level of adjustment in terms of their EB system. The system considers engine speed (RPM) and gear. Thus, giving the team freedom to configure an engine brake strategy for each of the six gears.

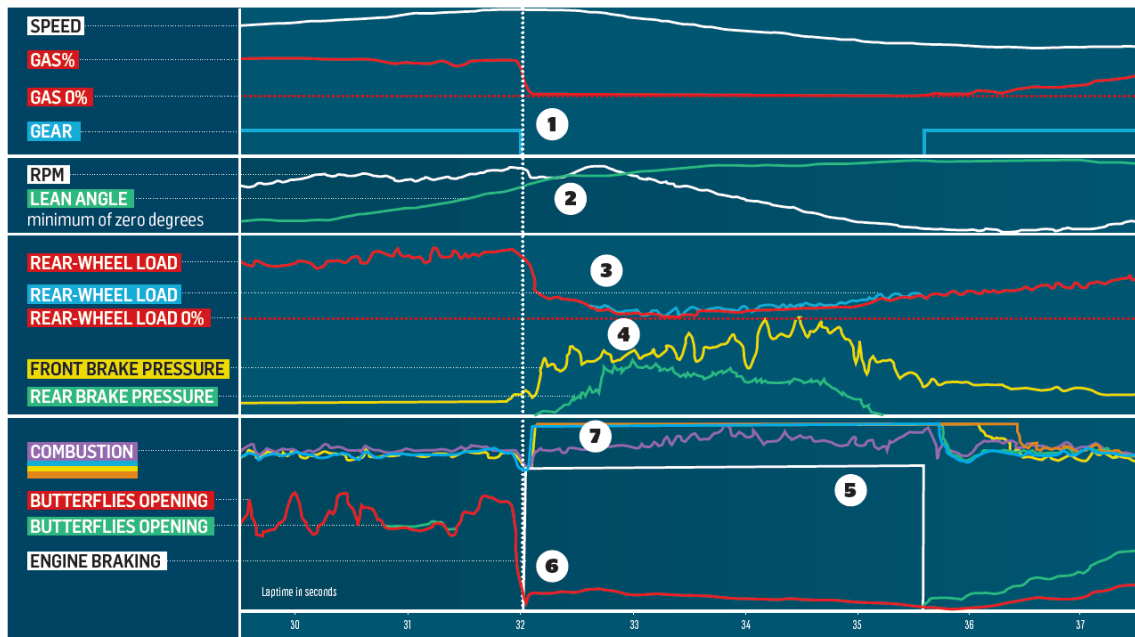


**Figure 6** - Example of EB becoming effective shown in an example data trace from Circuito de Jerez. ("How MotoGP engine-braking control works - Motor Sport Magazine," n.d.)

Figure 7 shows the EB strategy map within MoTeC M1 tune. The map shown was used throughout the 2022 BSB national superstock championship by the team. The map can also be viewed graphically in figure 7 below.

|         |         | Engine Speed Calculated [rpm] |      |      |      |      |      |      |      |      |      |      |       |       |       |       |       |       |       |       |       |      |
|---------|---------|-------------------------------|------|------|------|------|------|------|------|------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|------|
|         |         | 0                             | 3000 | 4000 | 5000 | 6000 | 7000 | 7500 | 8000 | 8500 | 9000 | 9500 | 10000 | 10500 | 11000 | 12000 | 13000 | 14000 | 15000 | 15500 | 16000 |      |
| Gear    | Sixth   | 0.5                           | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.7  | 0.7  | 0.7  | 0.7   | 0.7   | 0.8   | 0.9   | 0.9   | 1.4   | 2.0   | 2.7   | 3.1   | 3.6  |
|         | Fifth   | 0.5                           | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.7  | 0.7  | 0.7  | 0.7   | 0.7   | 0.7   | 0.9   | 1.5   | 2.0   | 2.5   | 2.9   | 3.1   | 3.6  |
|         | Fourth  | 0.5                           | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.7  | 0.8  | 0.9  | 0.9   | 1.0   | 1.3   | 1.9   | 2.8   | 3.8   | 4.8   | 5.6   | 6.4   | 7.4  |
|         | Third   | 0.5                           | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.6   | 0.7   | 0.8   | 1.0   | 2.7   | 4.0   | 5.4   | 7.4   | 8.0   | 10.0 |
|         | Second  | 0.5                           | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.6   | 0.6   | 1.2   | 2.6   | 4.3   | 5.7   | 7.3   | 8.7   | 9.3   | 9.9  |
|         | First   | 0.5                           | 0.5  | 0.5  | 0.5  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 1.4  | 2.2   | 3.1   | 3.8   | 4.2   | 5.1   | 6.0   | 7.2   | 8.6   | 9.5   | 10.4 |
|         | Neutral | 0.0                           | 0.0  | 0.0  | 0.3  | 1.4  | 1.4  | 1.4  | 1.6  | 1.6  | 1.6  | 1.6  | 2.1   | 1.9   | 2.6   | 3.7   | 4.8   | 5.8   | 6.7   | 7.6   | 8.5   | 9.4  |
| Default |         | 0.0                           | 0.0  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.5  | 0.6  | 1.0  | 1.0  | 1.2   | 1.0   | 1.4   | 2.1   | 3.0   | 3.8   | 4.9   | 5.9   | 6.7   | 7.4  |

**Figure 7** - MoTeC M1 EB map in table form from GR Motorsport BSB motorcycle.

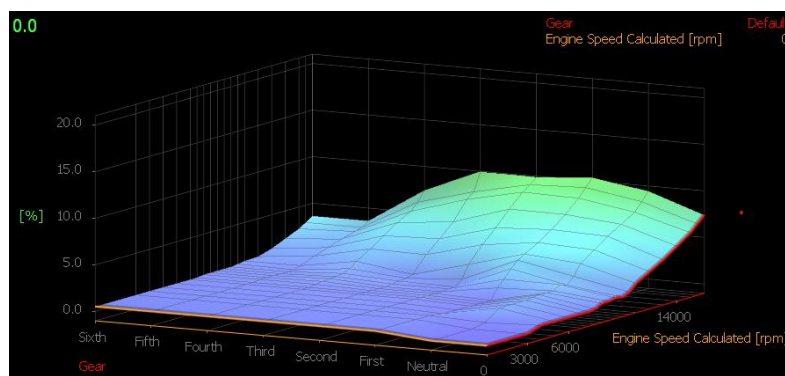


**Figure 8** - MoTeC M1 EB map in graph form from GR Motorsport BSB motorcycle.

## 2.3 Anti-Wheelie

Anti-Wheelie (AW) systems are another critical electronic control system that have been widely implemented across the motorcycle industry in recent years. AW systems offer stability during acceleration phases and sharp increases in throttle demand. When a rider is exiting a corner, throttle demand is high, and thus creates high rates of acceleration. During this acceleration phase, load is transferred to the rear of the motorcycle. This causes the front suspension to completely unload, and the front of the motorcycle goes 'light', this often drastically increases the tendency for the motorcycle to wheelie. ("Front and Rear Weight -Data For Motorcycles," n.d.)

Although wheelies look good and are often associated with a 'fast bike', they are undesirable and aren't effective when trying to achieve fast lap times. This is where AW systems are used in an attempt to keep the front wheel in contact with the asphalt as much as possible.

AW systems can be implemented through a range of techniques. In a paper published by Suzuki Motor Corporation in 2018, (Mase and Suzuki, 2018) explores the development of an AW control via two methods based on whether there was front lift (wheelie) detected or not.

One method used an open loop method using a vehicle dynamics model, which controls driving force that is delivered to the rider when request is made. Their alternative method used a closed loop model which was created using a combination of the dynamics model and an Inertial Measurement Unit (IMU) which is a sensor that measures acceleration in three axes, and a three-axis gyroscope so that angular measurements can be acquired. (Mase and Suzuki, 2018).

Justification for using both methods mentioned is so that there is constant feedback to the control system, allowing for a greater refined method of AW. Utilising only the open loop method would mean that there is a constant feedback to the ECU which determines when AW should be introduced. This then allows the ECU to deliver maximum allowable driving force for as much time as possible, rather than there being a constant restriction on driving force which would reduce acceleration capability.

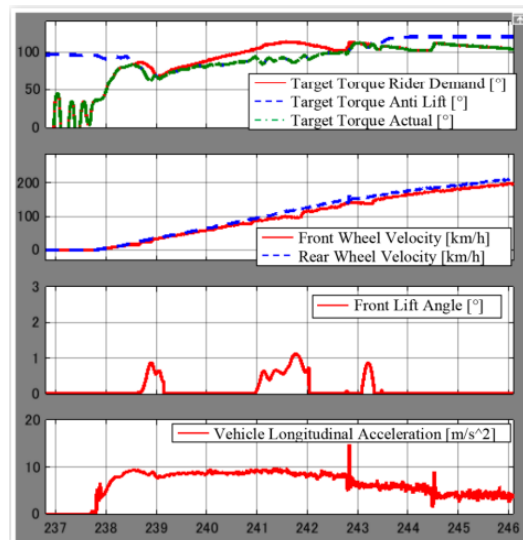


**Figure 9** - Suzuki lift control system data trace example. (Mase and Suzuki, 2018)

Commonly, AW systems consider RPM, front suspension position, pitch of the motorcycle, and gear to anticipate a wheelie and control it via closing one or multiple throttle bodies to reduce the amount of power and torque being delivered to the engine. This is like systems like traction control explained previous within this report. The following figure highlights an example where AW becomes active, as a MotoGP rider accelerates out of Sito Pons corner (turn 5) at Circuito de Jerez ("the circuit layout - Circuito de Jerez - web oficial," n.d.).

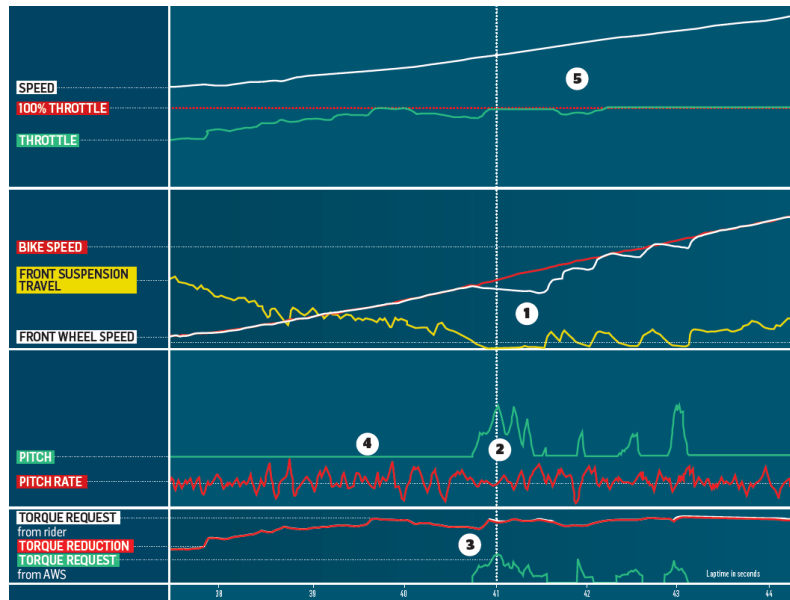


**Figure 10** - Example of AW systems becoming effective shown through an example data trace at Circuito De Jerez turn 5. ("How MotoGP anti-wheelie works - Motor Sport Magazine," n.d.)

## 2.4 Launch Control

Launch control systems are intended to allow the rider and machine to move from a stationary position as fast as possible to reach high speeds without the front wheel lifting or the machine getting out of control through wheel spin. The systems allow the motorcycle to move from a stationary position in a quick and smooth manner.

With launch control mode activated, it is possible for the rider to hold the throttle at maximum opening (100%) with the clutch engaged, and then release the clutch quickly while the ECU limits the level of power being delivered to the engine so that acceleration is as fast as possible whilst still remaining smooth and ultimately safe.

BMW M Race Calibration 2019 software has a launch control mode that 'holds the engine rev stable for the rider and to hold the rear wheel force (acceleration) at the highest possible level independently of the engine characteristic.' ("BMW M Race Calibration 2019," n.d.)

The system works through defining an 'allowable' rear wheel force (N) value at a range of pre-determined vehicle speeds (km/h) starting at 0 km/h and ending at 180 km/h. These values create a plot that the ECU follows to allow the motorcycle to accelerate as quickly as possible without giving the rider excessive rear wheel force and causing the motorcycle to wheelie and potentially loop out.

Strategy can be refined by altering the launch RPM, which is the value at which the ECU will limit the RPM prior to launch. Also required for this system is the engine rev limiter. It is also possible to set a pit lane limiter within this window, which are compulsory in most domestic racing championships for when the motorcycle is moving in pit lane. This launch system is deactivated automatically when either the engine is turned off, the motorcycle reaches third gear, or there is a wheelie of over 30 degrees detected. ("BMW M Race Calibration 2019," n.d.)

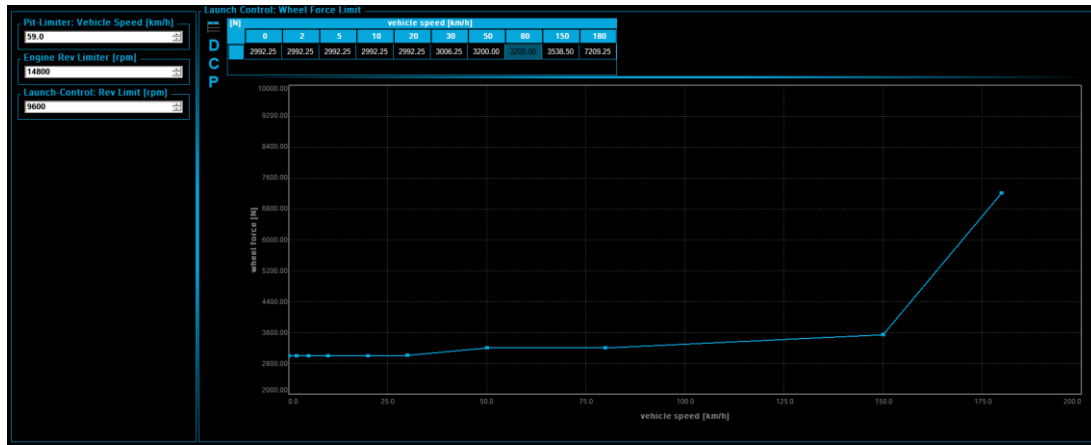


**Figure 11** - BMW M Race Calibration 2019 launch control mapping based on rear wheel force (N) and vehicle speed (km/h).

## 2.5 Ride by Wire / Throttle Mapping

Traditionally, motorcycles were equipped with mechanical throttle systems, using physical cables that ran from the throttle on the handlebar, down to the throttle body. These systems were used for a long time until manufacturers began to develop electronically controlled throttle systems, commonly known as Ride by Wire (RBW).

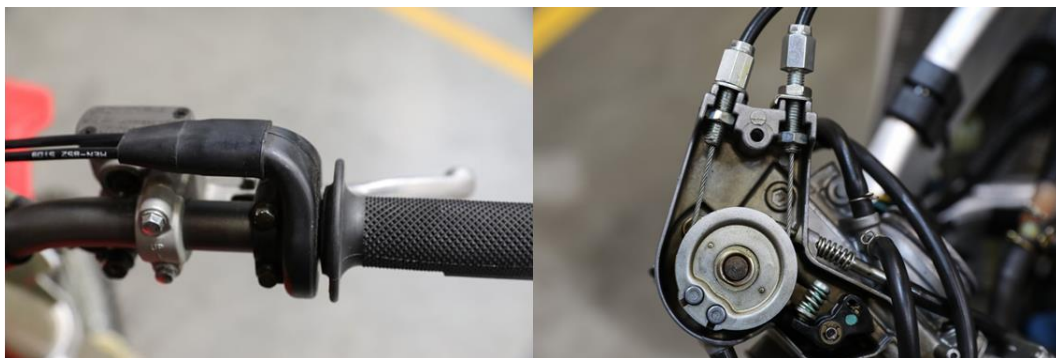


**Figure 12** - Traditional mechanical throttle system that uses a cable system ("How To Adjust and Replace Your Motorcycle's Throttle Cable," n.d.).

Yamaha were the first to develop a RBW system on their YZF-R6 motorcycle in 2006 ("This Is How Ride-By-Wire Technology Works," n.d.). Since then, they have become much more common with a vast majority of manufacturers and all of MotoGP teams using this system.

RBW throttle systems consist of sensors that feed information to the ECU, and actuators that receive information from the ECU which allow them to open and close the throttle butterfly. In RBW systems, air intake flow is controlled through an electronic device which replaces the traditional

mechanical throttle valve. Throttle butterflies are still utilised, however in RBW systems they are electronically controlled using a motor. Throttle position sensors are used to measure the opening angle of the throttle butterfly. (Wengert et al., 2007) .

The Yamaha RBW system previously mentioned was known as the Yamaha Chip Controlled Throttle (YCC-T) which featured a compact 32-bit Central Processing Unit (CPU) which governed each of the four throttle valves, one per cylinder. The system produced computations of input data every 1000<sup>th</sup> of a second that meant the system had much greater control on rider input and could deliver much more refined mapping accordingly. ("Electronically-Controlled Throttle | Yamaha Motor Co., Ltd.," n.d.).

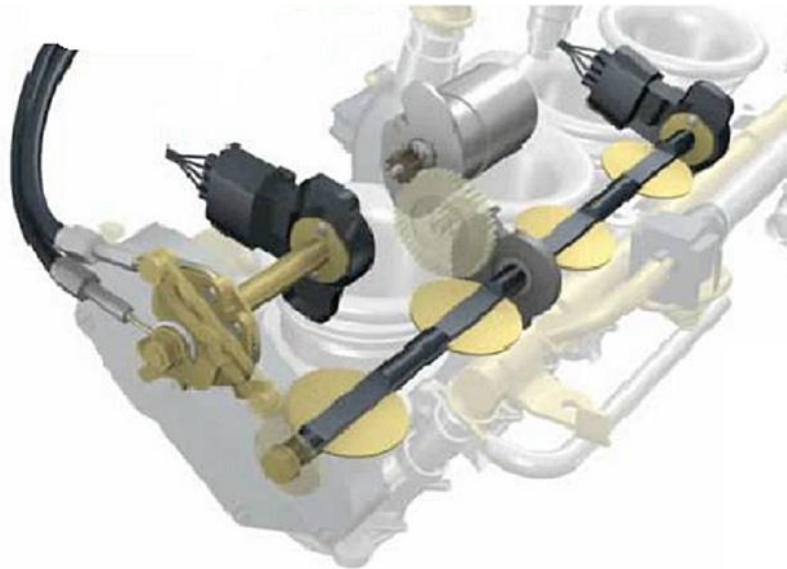


**Figure 13** - Yamaha YCC-T throttle system. ("Electronically-Controlled Throttle | Yamaha Motor Co., Ltd.," n.d.).

BMW motorcycles manufactured in 2019 onwards have an innovative method of throttle control through having what are known as split throttle bodies. These systems have two throttle body control motors instead of just one, like the Yamaha YCC-T system shown in figure 5. The BMW system instead utilizes one control motor for two cylinders, therefore meaning that two of the throttle butterflies are controlled independently to the other two. The main advantage of this system is that the rider or engineer now has full control over two banks of throttle butterflies and can map each 'bank' differently depending on RPM and throttle demand.

In racing contexts, World Superbike ("WorldSBK," n.d.) teams, specifically MV Agusta, Kawasaki, and Honda, used these split throttle body systems until 2017 when the FIM ("Home | FIM," n.d.) banned the systems. The reasoning behind this rule change was likely to create a more level playing field for all manufacturers and teams, meaning they had to control all throttle butterflies at once.

The use of split throttle body systems allows a rider to request high throttle demand during mid corner, and corner exit phases, without the rear wheel spinning excessively and over-wearing the rear tyre. Using throttle mapping tables, these systems can be used to determine how much butterfly opening the rider will receive compared with demand.

In a MoTeC M1 system , like the one used on the GR Motorsport Kawasaki ZX-10RR, these DBW maps can be completed for each gear, giving an even more refined level of control on power delivery.

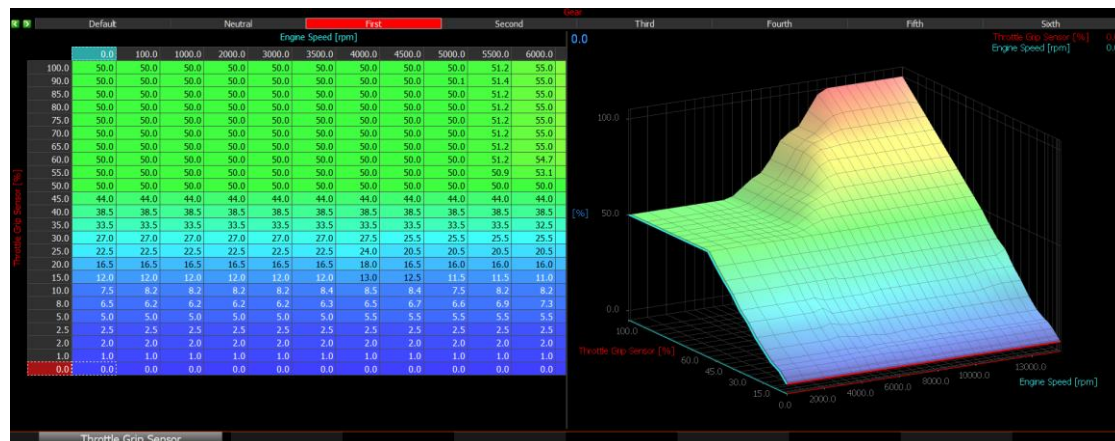


**Figure 14** - MoTeC M1Tune grip translation map for DBW throttle system used on the GR Motorsport Kawasaki ZX-10RR.

## 3 Methods

Within this section of the report, potential methods of work will be discussed and put forward as part of this overall proposal. It is worth noting that this section of work could be potentially flexible and be subject to change as the project progresses due to the shear flexibility that working with electronic control strategies and systems offer. It is also not possible to confidently predict the results that will be obtained from the work carried out.

### 3.1 Data collection

As previously mentioned within this report, data collection will predominantly be from GR Motorsport and their MoTeC i2 analysis and M1 Tune files that they will be collecting throughout the 2023 BSB season. This information will provide a comprehensive understanding of control systems and their strategies, how they can be altered and enhanced to obtain greater performance at racing circuits across the UK.

Data and information will also be collected wherever possible/applicable from the authors own private road racing team, WH Racing, from a 2016 Yamaha R6 600cc motorcycle and a 2021 Honda CBR-1000-RR-R SP motorcycle which will be equipped with 2023 HRC Kit electronics and a MoTeC L120 ("MoTeC > L120 > Overview," n.d.) logging unit.

Collection of data and information from different sources, motorcycles, and computer software can be seen as a benefit and something that will undoubtedly provide the best possible chance of achieving the aims of the project.

Information could also be retrieved from rolling road dynamometers, where motorcycles are subject to stationary testing with the rear wheel on a rolling drum. These dynamometers are highly suitable and widely used for collecting power and torque information for each RPM site in every gear. They are also extremely useful for fuel mapping and testing various DBW throttle maps.

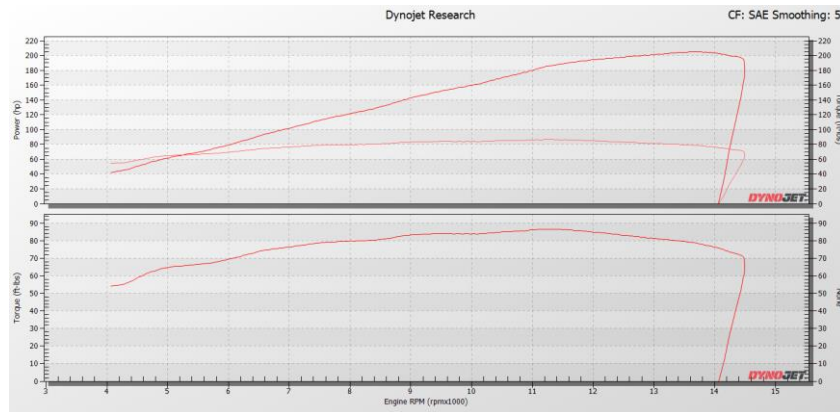


**Figure 15** - Power (top) and torque (bottom) curves taken from a DynoJet rolling road dynamometer from a Kawasaki ZX10-RR.

## 3.2 Data Analysis

Analysis of data gathered will be conducted using data analysis software, mainly MoTeC i2 and 2D WinARace (“WinARace — 2D Datarecording Documentation 1.0 documentation,” n.d.). Various channels and maps will be analysed along with the use of calculation/math channels wherever deemed necessary.

Analysis on the effectiveness of changes to a strategy or a system will be conducted throughout the project, with conclusions being drawn at each process to form the basis of any necessary improvements that could be made.

Various calculations could be considered to demonstrate areas of interest that perhaps aren’t included within the discussed software. Areas like torque demand would be of potential interest, where torque demand data could be tied to traction control and engine brake strategies to further improve the control that an engineer has over these control strategies.

## 3.3 Timing Plan

Included within this section is a timing plan for the entirety of the proposed project. The plan includes all proposed tasks and estimated timings. It is felt that all tasks have been given appropriate timings however it is possible that tasks could be completed in more or less time than what has been estimated within the plan.

| Major Project Research Proposal   |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
|-----------------------------------|---------|---|----|----|----------|----|----|----|-------|----|----|----|-------|----|----|----|-----|----|----|----|------|----|----|----|------|----|----|----|--------|---|----|----|-----------|---|----|----|----|
| Task                              | January |   |    |    | February |    |    |    | March |    |    |    | April |    |    |    | May |    |    |    | June |    |    |    | July |    |    |    | August |   |    |    | September |   |    |    |    |
|                                   | 2       | 9 | 18 | 25 | 6        | 13 | 20 | 27 | 6     | 13 | 20 | 27 | 3     | 10 | 17 | 24 | 8   | 15 | 22 | 29 | 5    | 12 | 19 | 26 | 3    | 10 | 17 | 24 | 31     | 7 | 14 | 21 | 28        | 4 | 11 | 18 | 25 |
| Electronic Control Systems        |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Electronic Control Strategies     |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Software Evaluation               |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Existing Strategy Consultation    |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Research Gathered                 |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Research Evaluation               |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Explore Possible Solutions        |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Major Project Work                |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Deadlines                         |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Research Proposal Presentation    |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Research Proposal Report          |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Major Project Proposed Start Date |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Major Project Report Submission   |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |
| Major Project Viva                |         |   |    |    |          |    |    |    |       |    |    |    |       |    |    |    |     |    |    |    |      |    |    |    |      |    |    |    |        |   |    |    |           |   |    |    |    |

**Figure 16** - Proposed major project Gantt chart.

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