



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

University of Wales Trinity Saint David
School of Engineering

Considerations in the development process of a
high-performance racing motorcycle for
competition road racing.

Dissertation
Master's Project
ACFA7003

Joshua Edward Watson
1900149
Supervisor: Andrew Harrison
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Declaration of Authenticity

'This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.'

Signed: Joshua Edward Watson

Date: 08/09/2023

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Abstract

Works within this report cover the process of building and developing a Honda CBR 1000 RR-R SP motorcycle for use within the 2023 road racing season by WH Racing Team and Julian Trummer.

Works within this report will cover the entire process of building the bike, starting with a completely standard road bike, and re-building it with aftermarket components. The report also covers the procedures involved with configuring and setting up the electronics and data logging packages, along with development of each electronics strategy that was available on the bike.

Included within the report are also all issues that were encountered throughout the project, including what the issue was, the reasons behind the issue, mitigation processes, and prevention methods to prevent a recurring issue.

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1 Introduction

In motorcycle racing, there are several key components that contribute toward overall success. Notable contributions are rider input, and teamwork. However, the key factor in achieving success is the motorcycle, how it was built, and the considerations that must be made to construct a machine capable of achieving high level results.

There are many disciplines of motorcycle racing, however this report is based solely within the context of 'road racing' at events including the Northwest 200, and the Isle of Man TT.

Motorcycle's that are at the top of their respective discipline are often considered to be 'fast' motorcycles, but tuned engines producing high power readings are not the only requirement for achieving these results. There are other areas that should be explored and considered accordingly which can also contribute toward the overall performance of the motorcycle.

Important areas to be considered when building a motorcycle for use within a high-performance racing context include:

- Ergonomics (rider position)
- Aerodynamics
- Powertrain
- Electronics systems
- Suspension systems
- Mass, Centre of Gravity (COG) position
- Tyres

Work documented within this report were predominantly centred around a 2022 Honda CBR-1000-RR-R SP, which was converted to a fully purpose-built racing motorcycle in April 2023. All work undertaken was conducted by the author, along with a professional motorcycle engineer with 30 years of experience in building and tuning high-performance racing motorcycles. The motorcycle is owned by a racing team known as WH Racing Team and was built to be raced by their Austrian racer Julian Trummer in the 2023 season. Following sections of this report document the process undertaken to build the motorcycle, including all development stages, Issues encountered along the way, and aim to document as accurately as possible all considerations that were taken along the way.

The primary aim of this report is to provide an in-depth exploration of the build, development, problem solving processes associated when building a high-performance racing motorcycle. Also, to be included within the report are honest reflections on each stage of the process including the opinions of the author and rider as the project progressed.



Figure 1 – Road going Honda CBR 1000 RR-R SP. [1]

Figure one shows a fully road going version of the ‘Fire blade’, figure two shows the initial state of the motorcycle explored within this report.



Figure 3 - WH Racing Team Honda CBR 1000-RR-R-SP motorcycle as the build process began in April 2023.

1.1 Project Outline

Upon receiving the motorcycle in early April 2023, as shown in figure two, the initial build process was spread over several weeks, in which the motorcycle was completely dismantled, and re-built using aftermarket racing components. Once the initial build process was complete, the motorcycle was used at multiple racing events including the Northwest 200, and the Isle of Man TT. To accurately present a timeline of the project, a diagram was created which included all significant milestones and their associated dates. The diagram can be observed below.

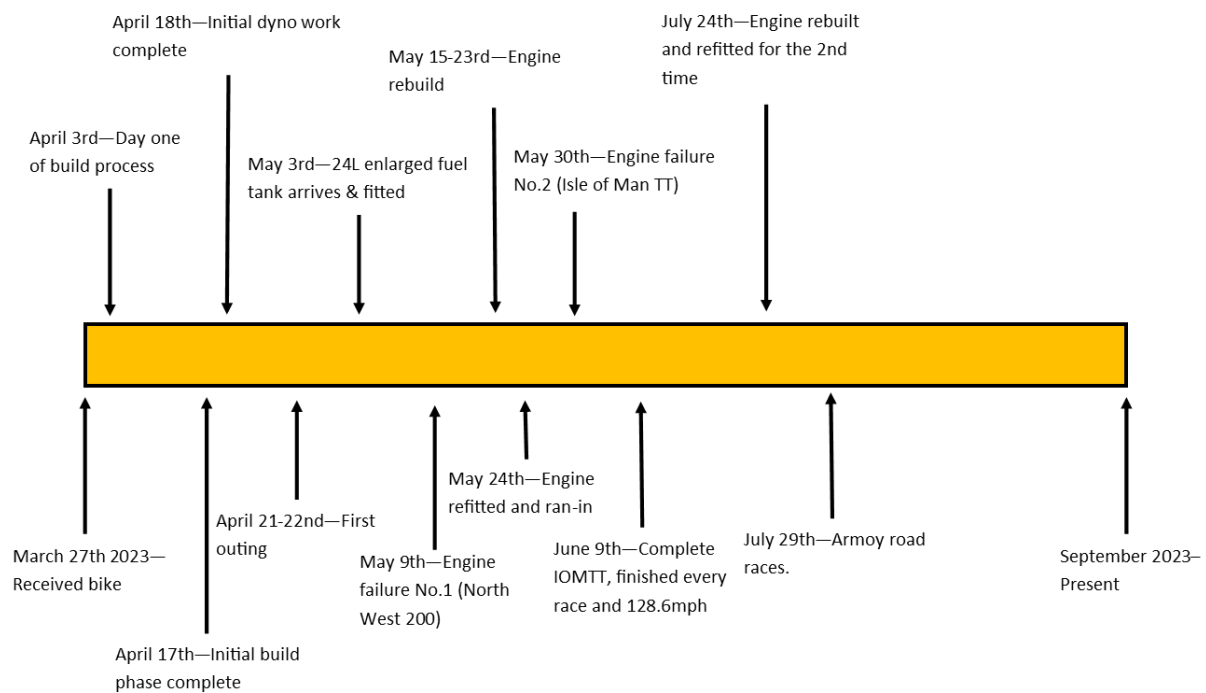


Figure 3 – Project timeline showing key milestones and their associated dates.

1.2 Aims and Objectives

There were several aims and objectives that were constantly considered and referred to throughout each stage of the project. As with any project, it was important to have a strict set of objectives outlined at an early stage, which would provide a good basis for evaluating the success of the project at each stage of the project. Referring to aims and objectives throughout, also ensured that the project remained relevant to the project motivation.

Aims:

- Provide insight into the processes and techniques used to construct and develop high performance racing motorcycles.
- To construct and develop a motorcycle that would be used throughout the 2023 racing season by WH Racing Team and Julian Trummer.
- Accurately investigate and mitigate any issues that may arise through the best possible solutions.
- Gain a comprehensive understanding of the Honda CBR-1000-RR-R SP motorcycle and its associated components.

Objectives:

- Use professional techniques and equipment to efficiently develop and run the motorcycle once the initial build phase was complete.
- Use MoTeC i2 data analysis software and MoTeC C125 dash manager software to configure and analyse the Datarecording equipment that the motorcycle would be equipped with.
- Evaluate and test various configurations of electronics strategies on the motorcycle and evaluate their success using rider feedback and research.
- Provide a comprehensive report on findings throughout the project, including honest reflection and non-bias opinions.

2 Initial Build

As mentioned previous, many aftermarket components are needed to convert a road going motorcycle to a competitive racing motorcycle. OEM components that come as standard on a road going motorcycle would be removed for several reasons including:

- Mass reduction
- Strength & durability
- Adjustment level
- Ease of use
- Performance

This section of the report has been written to outline each of the major components that were fitted, and to explain the reasoning behind the change and why it was necessary.

2.1 Suspension systems

The fundamental idea of utilising suspension systems on motorcycles is to create a scenario where the rider has maximum traction, reduced harshness, and consistent feel by absorbing bumps and discrepancies that the asphalt surface may have. Suspension systems are constructed using a spring, and a damper. Their sole purpose is to isolate the sprung mass of the motorcycle from the asphalt surface, whether it be a racing circuit in this context, or a normal public road. [2]

Sprung and Un-sprung mass

When discussing motorcycle suspension systems, two terms are commonly used: "sprung" and "un-sprung" mass. The parts that are directly attached to the frame of the motorcycle, such as the engine and its auxiliary parts, fuel tank, bodywork, and the rider among other components make up the sprung mass. On the other hand, the un-sprung mass refers to front and rear wheels and the parts directly connected to them, like axles, the lower part of telescopic forks, brake callipers, and part of the rear swingarm. [3]

In a perfect situation, the sprung mass should remain in a straight line as the motorcycle rolls along the road, and the un-sprung mass should move in a vertical direction over the bumps and surface discrepancies to maintain optimum performance. There are three forces associated with suspension systems, spring force, damping force, and friction forces. Springs used in racing motorcycles are most commonly coil springs, where their force is dependent on wire diameter, coil diameter, number of coils, and the material choice. Damping force is dependent on oil viscosity, orifice sizes of the valves inside the damper, piston dimensions, and the speed at which the system is operating in both compression (upward) and rebound (downward) directions. Frictional forces are resultant of the materials within the suspension system that are in contact with each other. [2]

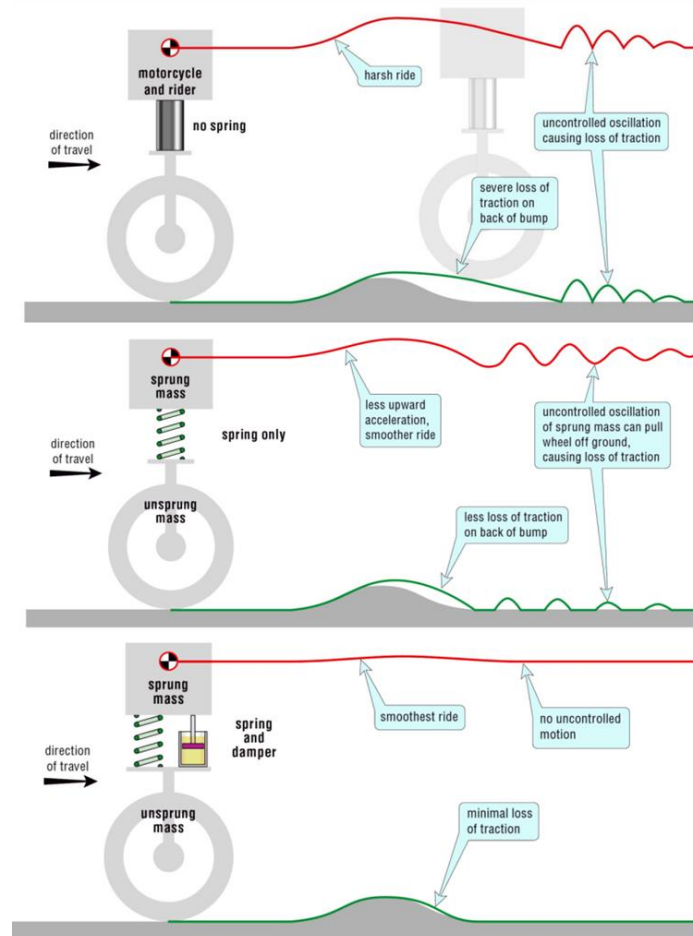


Figure 4 – Comparison on how sprung and un-sprung mass behaves when there is no suspension, only a spring, and spring and damper when a motorcycle hits a bump. [2]

Figure four shows how both sprung and un-sprung mass reacts when the motorcycle rolls over a bump, as it would in a real-world scenario.

The top section of the figure shows reaction when there is no spring or damper present. Due to their effectively being no suspension, a violent displacement is caused which sends the wheel upward toward the rider causing a loss of traction, when the wheel eventually returns to the asphalt surface, there is a bouncing sensation due to there being no damping force or spring force present.

On the middle section of figure four, a spring has been introduced to the system, which clearly shows a difference in the reaction of the system when it rolls over the bump. Still, the wheel moves in an upward direction, but it is less than that movement without any suspension system at all and is less violent. With a spring, there is reduced loss of traction, however oscillation occurs which can become un-controllable through the sprung mass of the motorcycle, which can cause a reduction in traction. Generally, with a spring, a smoother ride is created.

Finally, in the lower section of figure four, a damper has been added to pair with the spring that was introduced previous. Utilisation of a spring and damper combination provide the smoothest ride possible, however still do not completely remove all the negative behaviour from the system. In that scenario, sprung mass still moves in an upward direction when the system hits the bump, however when the wheel regains its contact patch with the ground surface, it can retain contact therefore maintaining traction and resulting in a minimal loss of traction.

As demonstrated above, inclusion of damping is vital to creating a scenario where the suspension systems can behave in a desirable manner. Often, dampers have a range of adjustability where spring preload, compression, and rebound damping can be adjusted to refine the behaviour of the system. [2]



Figure 5 – Ohlins RSP40 rear shock absorber developed solely for racing purposes and used by many high-level racing teams around the world. [4]

Figure five shows an Ohlins RSP40 rear suspension unit, commonly known as a ‘shock absorber’. The RSP40 features full adjustability in terms of damping, spring rates and preload, and unit length and is made exclusively for racing purposes by high level teams at world championship level. The shock absorber is machined from high quality materials and is machined from solid and constructed with a 40mm diameter piston running through the middle [4]. All those attributes mentioned above are typically common of rear suspension units specifically manufactured for racing purposes. The right-hand side of figure five shows both compression (gold) and rebound (silver) adjusters which both can be adjusted to either open or close the compression and rebound valves within the damper body, therefore adjusting the behaviour of the unit.

Compression and rebound valves work by allowing suspension oil to pass through holes machined into a piston depending on how open or closed the valve is. Compression valves work when the suspension unit is compressing (moving in an upward direction), and rebound valves work when the suspension unit is returning to its original length (moving in a downward direction). They are often adjusted through ‘clickers’ like the ones shown in figure five, which turn on a click mechanism to

either open (anti-clockwise) or close (clockwise) the piston. Typically, these adjusters have a range of around 30 clicks. If an adjuster is more open, then more suspension oil is allowed to pass through orifices in the piston easier decreasing the damping effect, and alternatively if the adjuster is in a more closed position, then it is harder for oil to pass through the orifices and therefore increasing the damping effect. This can also be further refined internally by adjusting the shim stacks on the compression or rebound valves, with stiffer or lighter shims and shim configurations, the same effect is achieved as to adjusting the adjusters, while keeping a wider range to adjust externally. This is particularly useful when there are time constraints and there is not enough time to have the valve shim stacks altered.



Figure 6 – Piston as found in front and rear suspension units containing orifices that allow oil to pass through them, allowing the suspension to work. [5]

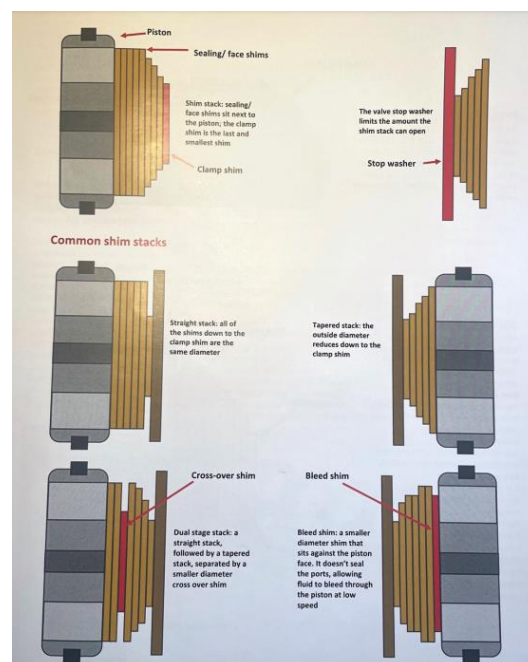


Figure 7 – Common configurations of shim stacks found in suspension units, different shim stack configurations can be used to adjust the behaviour of compression and rebound valves. [6]

For this project, suspension units from K-tech Suspension [7] were used. Due to superstock technical regulations, where the category is based on a road going motorcycle with some components being allowed to be changed, they stipulate that the front fork body must remain as standard, however the internal workings of the fork may be changed. Using this information, a K-tech DDS (Direct Damping System) cartridge kit was fitted. This kit is a 'complete replacement damping system designed and manufactured in the UK for high end racing applications.' [7]



Figure 8 – K-tech DDS front cartridge kit that was installed on the WH Racing Honda CBR 1000-RR-R SP. [8]

As figure eight shows, the kit is capable of everything that would be required of it within the context of this project whilst still being within the provided superstock regulations which the bike would have to meet for events like the North West 200 and Isle of Man TT. It was also worth considering what support packages would be available whilst specifying suspension systems for the project. Whilst at the race events, it is important that there is support on hand from suspension companies in case of problems with components or if setup advice was required. This was deemed to be a big advantage when choosing to go with the K-tech product over other suspension companies, since there is a highly efficient support network readily available at all events to anyone that utilises K-tech products.



Figure 9 – K-tech DDS Pro rear shock absorber that was installed to the WH Racing Honda CBR 1000-RR-R SP. [9]

Figure 9 shows the rear suspension unit that was used for the project, which was also manufactured by K-tech suspension. The DDS Pro rear shock has all methods of adjustability necessary and utilises a bypass valve system (red adjuster), which allows for adjusting both compression and rebound damping at the same time to assist chassis behaviour at lower speeds, which therefore increases rear tyre grip and feeling. Using a 32mm piston rod also allows for larger shims to be used in the unit, also increasing feel [9]. It was worth noting that to be able to change the spring on the unit, a specialist spring compressor had to be purchased from K-tech, allowing safe and quick spring changes when needed at the circuit.

Figure 10 – K-tech Suspension spring compressor tool that was needed for any spring changes whilst at race events. [10]



2.2 Exhaust System

Standard road going exhaust systems are designed so that they meet required emissions standards, which currently means that the standard 2022 Honda CBR-1000-RR-R SP meets Euro 5 emissions standards and is equipped with a relatively large catalytic converter [11]. In a racing context, there are no restrictions or standards surrounding emissions that must be met, meaning that carrying a heavy exhaust system was deemed to be un-necessary and detrimental to the power output of the motorcycle.

A full aftermarket exhaust system was fitted, produced by Akrapovic and made with stainless steel headers and a titanium silencer. The system has been developed purely for racing uses and is not suitable for meeting any emission compliance requirements for road use. Over the standard exhaust system, the Akrapovic system offered an 11.9kW (15.95bhp), and 14.4Nm increase whilst also being 0.8kg lighter [12]. To optimise the performance of the exhaust system, Akrapovic recommend remapping the ECU of the motorcycle. This will be covered in later sections of the report.



Figure 11 – Akrapovic exhaust system [12]

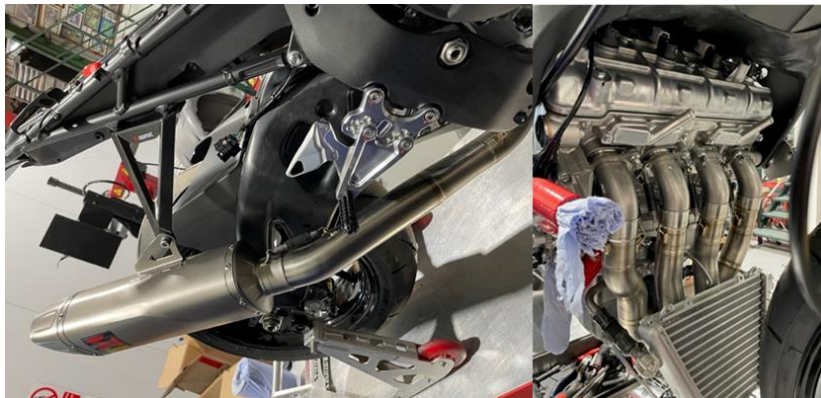


Figure 4 - The exhaust system fitted to the WH Racing Honda CBR 1000-RR-R SP.

2.3 Electronics and Data logging Packages

Most modern motorcycles are equipped with vast amounts of electronics, including instruments and rider aids like traction control, wheelie control, and much more. In racing contexts, electronics are one of the most vital pieces of the puzzle to constructing and running a high-performance motorcycle. From the early 2000's, electronic fuel injection has been a common feature on motorcycles around the world. ABS (Anti-lock braking systems) have also become much more common, along with traction control and other rider aids that were all developed to improve the performance of the motorcycle [13]. Considering this information, it was deemed vital that the WH Racing Honda CBR 1000-RR-R SP should be fitted with the best possible electronics package to enhance performance as much as possible whilst containing high levels of adjustment capability.

Only discussion on the electronics package chosen will be given within this section of the report. A following section will be included to give thorough explanation of each electronic strategy, how they are implemented, and the work that was undertaken to develop and understand them in racing scenarios throughout the 2023 racing season.

Most motorcycle manufacturers offer a 'kit' electronics package for their motorcycles, which commonly consists of a wiring loom and ECU (Electronic Control Unit), software for adjusting parameters, and a communications cable that goes from a laptop to the motorcycle.

Another benefit of utilizing the HRC kit electronics software, is that the wiring loom is much smaller and concise, since it only contains the necessary connectors for the running of the motorcycle. All road going connectors are removed due to their use no longer being required. This also meant that there was a mass saving, which as previously mentioned, helps greatly in racing.



Figure 13 – HRC kit wiring loom and ECU. [14]

Data logging Package

Data logging or acquisition as it is commonly referred to, is the process of storing data from sensors and potentiometers mounted to the motorcycle which accurately measure parameters of the bike which can be then downloaded and analysed at the end of a session or run. The information gathered helps engineers and technicians to make decisions based on how the machine and rider are performing on track. Using GPS, it is possible to view the path that the motorcycle has followed, (the circuit) and the data gathered can be split into individual laps for greater accuracy when analysing [15]. There are several purposes that the data logging equipment can be used for:

- Performance analysis
 - Lap time
 - Sector timing
 - Speed
 - Gearing ratios
- Rider analysis
 - Lap comparison
 - Braking phases
 - Mid-corner phases
 - Corner-exit phases
- ECU data
 - Engine parameters
 - Strategy evaluation
- Suspension
 - Position
 - Velocity
- Diagnostic checks
 - Coolant temperature and pressure
 - Oil temperature and pressure
 - Lambda (fuelling)
 - Airbox temperature and pressure

There are many different electronics packages to choose from, all manufactured by different companies and offering different levels of performance based on the level of racing that the motorcycle is intended for. Some more basic packages offer far less analysis capabilities and are tailored more toward clubman/novice racing teams. Then there are also very advanced logging

packages that are made by companies like MoTeC [16], Magnetti Marelli [17], and 2D Datarecording [18]. These packages offer extremely detailed levels of analysis and there are endless amounts of parameters that can be logged through multiple different sensors and potentiometers.

At the time of this project, there were hardware shortages making datalogging equipment increasingly difficult to obtain, this meant that extra consideration had to be given about having a full logging package installed and working on the motorcycle when it headed to its first race meeting in April 2023. And with cost, and usability also being brought into consideration, it was decided that a MoTeC L120 logging system would be installed for the project.

After some market consultation, it was discovered that Mototronics [19], a UK company would be able to supply all hardware for the MoTeC L120 data logging system without major time delays. The following figure outlines the specified system configuration that was decided and all components that would be installed to the motorcycle.

Description	Price	Quantity	Price
L120 Logger with I/O & 120mb*	£ 1,250.00	1	£ 1,250.00
Pro Analysis	£ 701.00	0	£ -
KTC - Suzuki only	£ 295.00		£ -
Relay - Suzuki only	£ 45.00		£ -
SLM Shift Light Module	£ 317.00		£ -
GPS L10	£ 100.00	1	£ 100.00
LTC Lambda Controller	£ 314.00	1	£ 314.00
Harness	£ 350.00	1	£ 350.00
F Pot	£ 175.00	1	£ 175.00
F Pot Carbon Sleeve	£ 30.00	1	£ 30.00
R Pot	£ 175.00	1	£ 175.00
Brake Pres	£ 310.00	1	£ 310.00
Comms Lead	£ 100.00	1	£ 100.00
Rain Light	£ 75.00		£ -
LSU 4.9 Lambda Sensor	£ 100.00	1	£ 100.00
TOTAL			£ 2,904.00

Figure 14 – MoTeC L120 data logging hardware components quotation from Mototronics.

An added advantage to installing the MoTeC system was that the author of this report had prior experience with the MoTeC i2 analysis software. This meant that it was a more seamless process when configuring and working with the equipment throughout the 2023 season. It was also worth noting that the software itself is free to download from the MoTeC website.

To suitably install the data logging equipment, some brackets were made so that the L120 logging unit could be mounted at the front of the motorcycle, where it could be connected into the designated connector within the HRC kit wiring harness. A communications plug was also installed in the dashboard mounting plate so that there would always be easy access when data retrieval was required after a session.



Figure 15 – MoTeC L120 logging equipment mounted to the motorcycle.

Figure 15 shows the MoTeC L120 data logging equipment mounted to the motorcycle, including linear potentiometers to both front and rear suspension units, as shown on the right section within figure 15. The purpose of linear potentiometers on suspension is so that suspension position and velocity can be always measured. These potentiometers read data at high frequencies due to the speed and frequency at which the suspension is being compressed and rebounded whilst the motorcycle is in use. Commonly these potentiometers are set to record data at a sampling rate of 200Hz. [13]

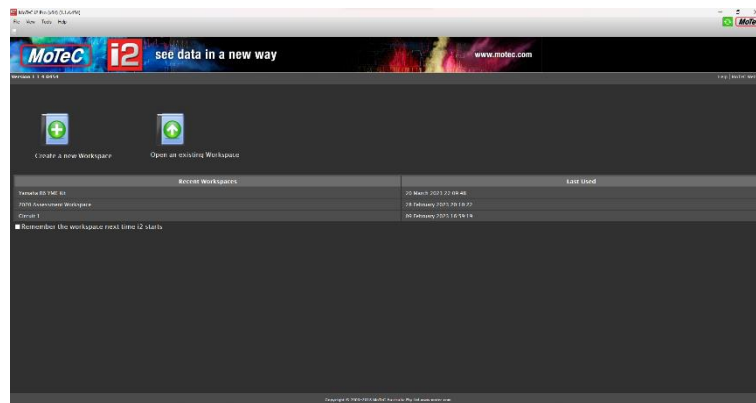


Figure 16 – MoTeC i2 data analysis software home screen.



Figure 17 – Example data screen showing suspension data within MoTeC i2 data analysis software.

2.4 Ergonomic and Miscellaneous Components

There are many miscellaneous components that were fitted to the motorcycle, including some ergonomic parts like adjustable handlebars, footrests (rear sets), final drive chain and sprocket set, quick action chain adjusters, braided brake lines, bodywork, air filter, and coolant hoses.

All the above listed components are important considerations to make for different reasons. Some components like the air filter, and chain and sprocket kit are performance gaining components, whereas other components were included due to reliability, aesthetics, durability, and weight saving. Images of the entire build process can be viewed below.



Figure 18 – Day one of the build process.

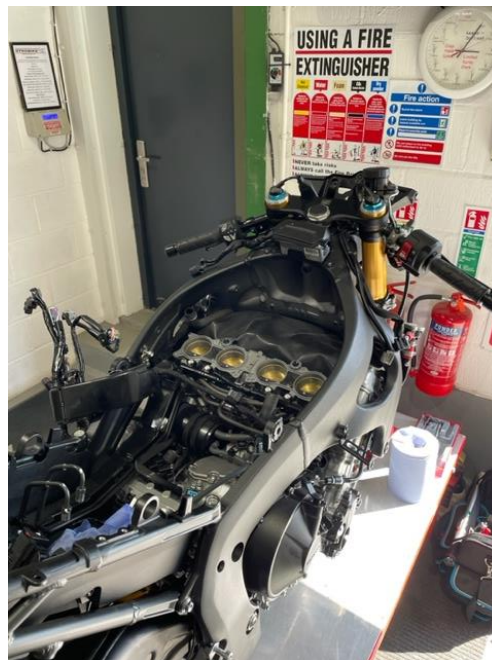


Figure 19 – Strip down of bike ready to remove standard wiring loom & ECU.



Figure 20 – All wiring and components fully removed and ready to install HRC kit wiring harness.

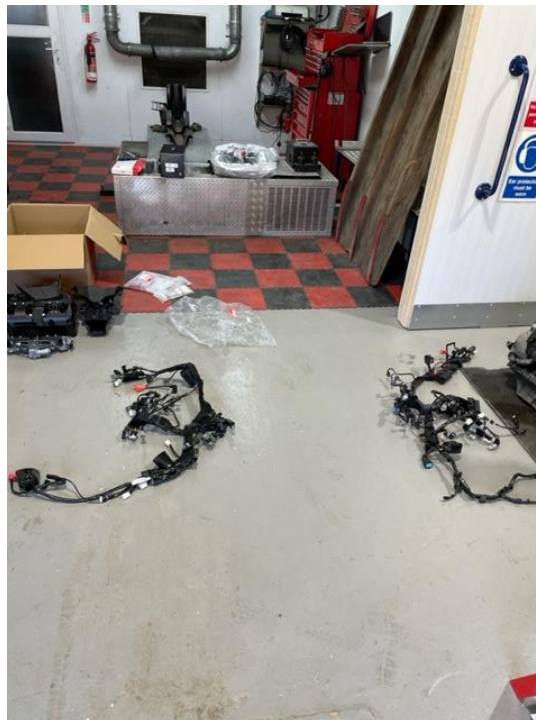


Figure 21 – HRC kit wiring harness (left), and standard wiring harness (right).



Figure 22 – HRC kit wiring installed and re-installing throttle bodies.

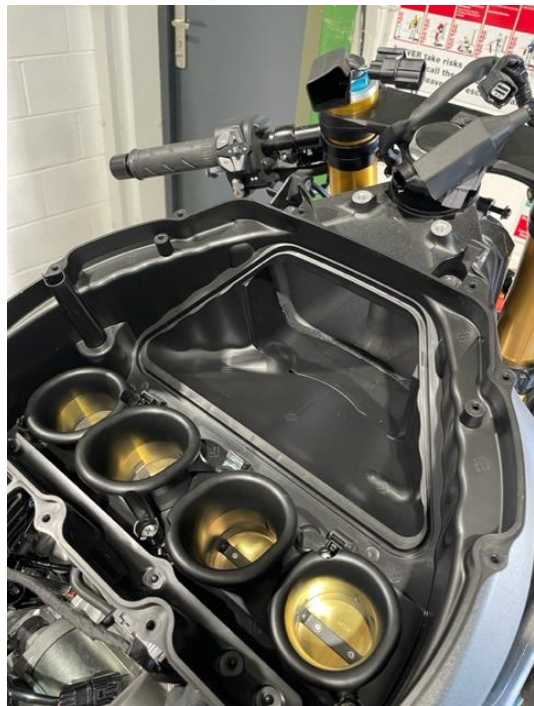


Figure 23 – Bottom half of airbox reinstalled, throttle bell mouths installed.



Figure 24 – Sprint aftermarket air filter installed.

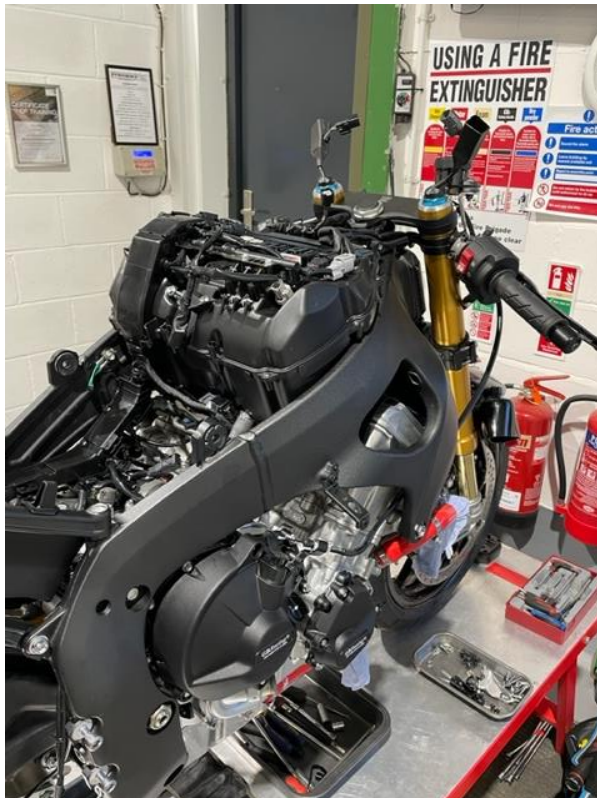


Figure 25 – Wiring harness installation complete, airbox completely rebuilt and all connectors installed.



Figure 26 – Front end components installed including Brembo T-Drive discs, braided brake lines, and drilled stainless steel brake calliper mounting bolts.



Figure 27 – Engine protection and silicone coolant hoses installed.



Figure 28 – Exhaust system being installed.



Figure 29 – Handlebars and other ergonomic components fitted.



Figure 30 – Build process nearing completion.



Figure 31 – Bodywork mounted for the first time.



Figure 32 - Completed build on the eve of the 2023 Cookstown 100.

3 Setup and Configuration

3.1 Running In

Once the motorcycle had been built as shown in the previous section of this report, there was still some work to complete before it would be ready for racing use. Since the bike was brand new to the team, the engine arrived with 0 miles, which therefore meant that it required 'running in'. The running in process was completed over a period of around two hours on a rolling road dynamometer. The main purpose for running in the engine was for safety reasons, to ensure that all components were working correctly and that there were no major issues with the construction of the bike. Running the bike in allowed all internal engine components to wear in with each other sufficiently, especially the pistons, piston rings, and cylinder bores [20]. If the process was not completed correctly, then it could have been detrimental to the health of the engine over time and affect performance levels.

The process was completed whilst holding the bike at low load and ensuring to run the bike in each gear at low load a few times, so that all components could bed in with one and other. It was vital to keep throttle opening low. After around 45-50 minutes of low load running in, it was necessary to use slightly higher load through each gear. Constant exposure to constant rpm under light load can cause some issues internally, including glazing on the cylinder bores, which can cause further issues with piston rings. [20]

It was also worth noting that the entire running in procedure was completed using the standard engine oil, which is known as a 'running in oil'. It was necessary to complete this process using a running in oil as it allowed some light wear to components, which helps with the bedding in process. Using an extremely high-quality engine oil during running in can prevent this light wear and prevent the running in process from being as effective as it should be.

Following this running in period, the motorcycle had covered around 200-250km. It was then possible to begin the initial mapping and fuelling process.



Figure 33 – Running in process on a rolling road dynamometer at Dynobike Performance Tuning in Malton, North Yorkshire.

3.2 Electronics configuration

On the Honda CBR 1000 RR R SP, when using the HRC kit electronics package, adjustments are made using the HRC Data Setting Tool software. Within the software, many adjustments can be made to various electronic strategies and control systems, all of which can be used to refine the way in which the motorcycle behaves on track. Commonly changes are made based on the opinion of the rider, and based on information gathered from the MoTeC L120 logging system.

Initially, a 'base' file was provided from Gesslpower [21], an Austrian motorcycle dealership where the motorcycle was purchased from. The base map was utilised to gain a starting point on fuelling and other parameters, from which changes could be made depending on how fuelling was analysed using Dynojet [22] rolling road dynamometer.

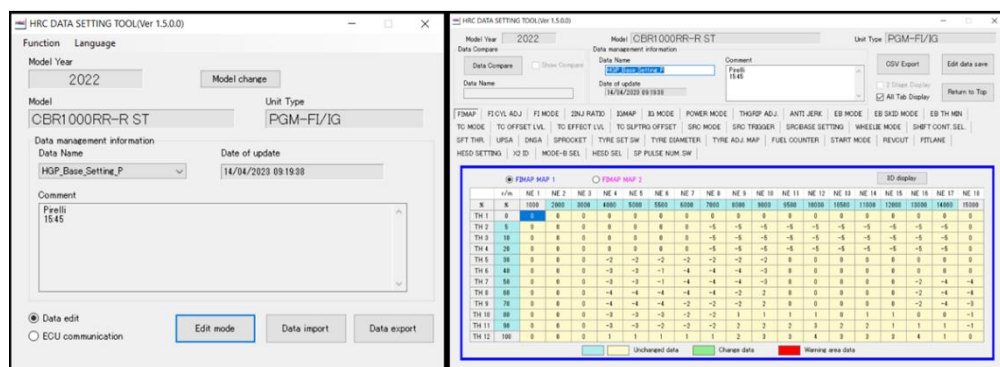


Figure 34 – HRC Data Setting Tool software used for adjusting the motorcycle through the HRC kit electronics package.

To ensure that the MoTeC logging system was working correctly, MoTeC C125 Dash Manager software had to be used. This is due to the L120 logging unit being constructed the same as a C125 dashboard without the screen. A configuration file was required that was relevant to the Honda CBR 1000 RR-R SP. This configuration file contains all relevant information regarding the electronics of the motorcycle, so that the software was aware of which sensor is connected to which input in the logger, as well as the calibration of each sensor. The configuration file also contained information so that the logger understood how, and where to display information. Other parameters like sampling rate, warning alarms and shift lights can all be configured through the configuration file [23].



Figure 35 – MoTeC C125 dashboard. [24]



Figure 36 – MoTeC L120 logging unit. [25]



Figure 37 – MoTeC C125 Dash Manager software which was used to control the MoTeC L120 logging system.

3.3 Initial Dynamometer Set-up

Initially, after the running in process had been complete, it was time to begin with initial setup of the fuelling of the motorcycle whilst on the rolling road dynamometer. It was deemed vital that the fuelling was correct since there had been many components changed during the build of the motorcycle. Most commonly, fuelling maps are adjusted based on injector opening time with throttle position, airbox pressure and engine speed. Within the HRC Data Setting Tool software, the fuel injection (FI) map is adjusted based on engine speed, represented as NE (Number of Engine Revolutions), and TH (Throttle Segmentation).

Data can be changed by percentage from a 0 value which represents standard fuelling. Positive values represent an addition of fuel, and negative values represent a reduction in fuel. The software displays twelve throttle positions for which data can be changed, and data can also be changed from 1000rpm through to 15000rpm.

FIMAP MAP 1		FIMAP MAP 2		3D display																
r/m	NE 1	NE 2	NE 3	NE 4	NE 5	NE 6	NE 7	NE 8	NE 9	NE 10	NE 11	NE 12	NE 13	NE 14	NE 15	NE 16	NE 17	NE 18		
%	%	1000	2000	3000	4000	5000	5500	6000	7000	8000	9000	9500	10000	10500	11000	12000	13000	14000	15000	
TH 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
TH 2	5	0	0	0	0	0	0	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	0	
TH 3	10	0	0	0	0	0	0	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	0	
TH 4	20	0	0	0	0	0	0	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	0	
TH 5	30	0	0	0	-2	-2	-2	-2	-2	-2	0	0	0	0	0	0	0	0	0	
TH 6	40	0	0	0	-3	-3	-1	-4	-4	-4	-3	0	0	0	0	0	0	0	0	
TH 7	50	0	0	0	-3	-3	-1	-4	-4	-4	-3	0	0	0	0	0	-2	-4	-4	
TH 8	60	0	0	0	-4	-4	-4	-4	-4	-2	2	0	0	0	0	0	-2	-4	-4	
TH 9	70	0	0	0	-4	-4	-4	-2	-2	-2	2	0	0	0	0	0	-2	-4	-3	
TH 10	80	0	0	0	-3	-3	-3	-2	-2	1	1	1	1	0	1	1	0	0	-1	
TH 11	90	0	0	0	-3	-3	-2	-2	-2	2	2	2	3	2	2	1	1	1	-1	
TH 12	100	0	0	0	1	1	1	1	1	2	3	3	4	3	3	3	4	1	0	

Figure 38 – Base fuel map which was used as a starting point during the initial setup process.

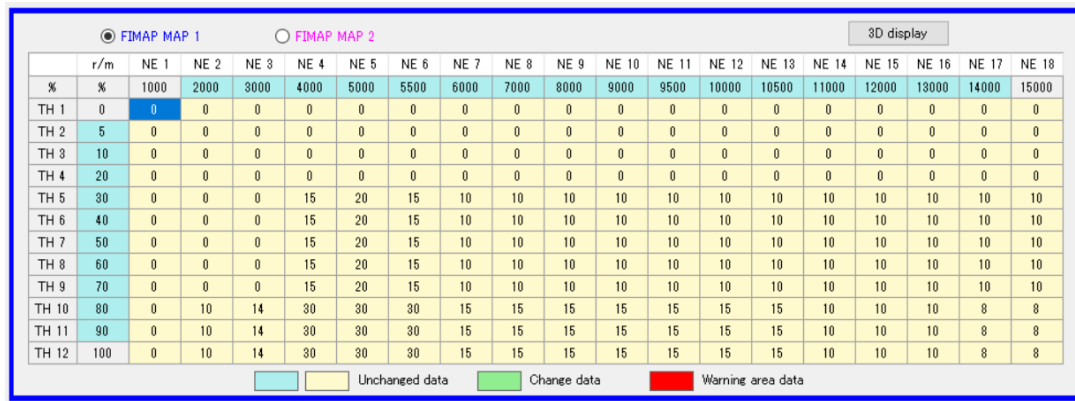


Figure 39 – Fuel map which was adjusted based on the base map and used at the Cookstown 100.

Lambda sensors are used on the rolling road dynamometer (dyno) which give air fuel ratio readings which can be used by the dynamometer operator to adjust fuelling maps accordingly. The aim was to maintain an air fuel ratio that remained around stoichiometric, which for petrol is around 14.7:1 [13]. Since the dyno operator can see real time data, this gives an accurate representation of how the fuel map can be adjusted to improve the performance of the motorcycle. Removing fuel from the cylinders makes the mixture lean, which can be used to improve fuel consumption, however, can increase temperature within the engine and eventually cause engine damage. Adding fuel to the cylinders makes the mixture rich, which can help to reduce temperature in the engine, however, increases fuel consumption, something that is not desirable when racing at the Isle of Man TT.

Whilst conducting testing on the dyno, it was desirable that the lambda reading remains around 1.00, which indicates chemically perfect combustion, however when at full load during a horsepower run on the dyno, a lambda reading of around 0.860 [13]. It is also worth noting that included within the MoTeC L120 logging system, a MoTeC LTC 4.9 lambda measurement unit and sensor [26] were installed, which were used to measure lambda readings which could then be analysed using i2 analysis software.



Figure 40 – MoTeC LTC 4.9 lambda measurement unit and lambda sensor used on the project.

Using the dyno to accurately refine the fuelling allowed for an increase in power reading, improved torque output, and a consistent fuelling reading through all rpm ranges. To ensure that readings would be consistent, a dyno tyre was used, which is a road going tyre with a very hard compound, much harder than a race use tyre would be. This was used to keep power losses through the tyre to a minimum. Race tyres are very commonly built with no tread, and a very soft inner structure, which when exposed to extreme temperature like they are on the dyno, become very soft and spin, causing power loss.

Following the running in process and several dyno runs which were used to set up the fuelling of the motorcycle, a power reading of 216 bhp was achieved, which was an increase of around 3 bhp. There was also significant improvement in power delivery due to fuelling changes, and torque output was also improved dramatically over initial results.

4 Development Issues

To provide fair context, initially the project was running smoothly and there were no issues. All initial setup procedures and dyno work was completed with promising results which provided the team with some great motivation that the 2023 season was going to be a resounding success. Upon arriving at the Cookstown 100 it was anticipated that there may be some small adaptations to make, which was to be expected since the motorcycle was brand new with no prior testing in a racing scenario. This section of the report has been written to discuss any development issues that have occurred during the process of the project, and to ultimately give fair representation of the issues that can present themselves while constructing and developing a high-performance racing motorcycle.

4.1 Initial Issues

Following the first practice sessions that the motorcycle was used in, there were some small 'teething' issues that required solving. Primarily, based on Julian's feedback, the main issue being that the quick shift, and auto-blip systems were not working as they should be. This meant that Julian was forced to use the clutch for both up shifting and down shifting through the gearbox, which should not have been the case. The issue became apparent as when the motorcycle was running, the gear position indicator was not functioning correctly and instead of showing a solid gear, the display would 'blink', indicating that the ECU did not correctly recognise which gear it was in at any time.

As mentioned, the purpose of the quick shift and auto blip systems are so that the rider does not need to use the clutch when changing gear in both upward and downwards directions. The systems are commonly constructed using a load sensor on the gear shift shaft on the engine, and the ECU of the motorcycle which receives and sends the signals to control the system. When there is a force applied to the shift lever, a load sensor is either compressed or extended which causes a voltage change which remains in proportion to the force that has been applied to the lever. The ECU then recognises this change in voltage and allows the shift strategy to work. This strategy can be applied in different ways, commonly through cutting ignition whilst up shifting, and a brief increase in throttle whilst shifting downwards through the gearbox [13].

Within the HRC Data Setting Tool software, up shift strategies are implemented by adjusting torque reduction, or torque recovery. Torque reduction can be used to adjust how long torque is reduced for during an up shift, Increasing the value increases the torque reduction time, whereas reducing the value decreases the torque reduction time. Torque recovery values represent the amount of time that it takes for full torque output to be restored. Increasing torque recovery values reduces the time taken for full torque to be restored, and reducing the value increases the time taken for full

torque to be restored. Within the software, there is a range from +4 to -4. Therefore, implementing a strategy of -4 torque reduction, and +4 torque recovery would result in the shortest shift time. [27]

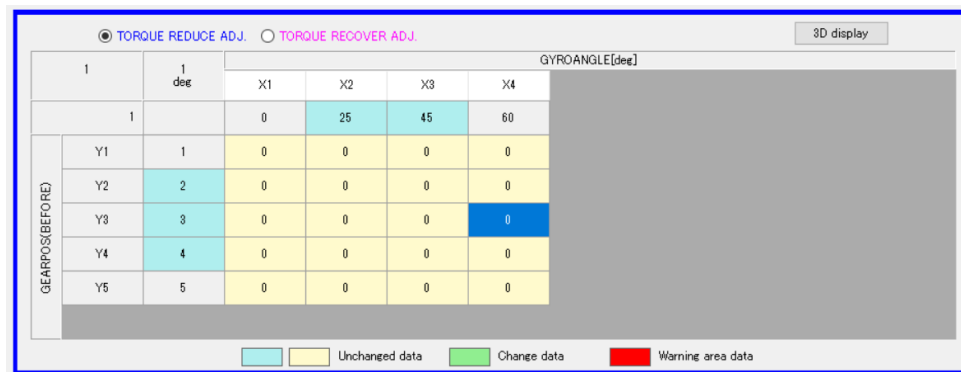


Figure 41 – UPSA (Up Shift Assist) strategy screen within HRC Data Setting Tool software.

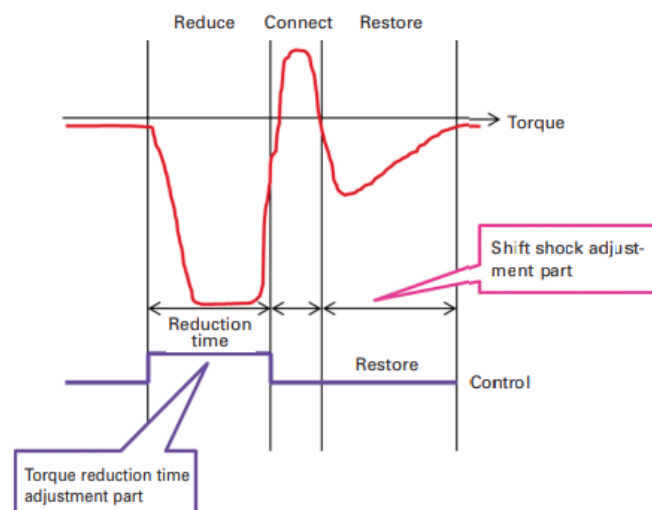


Figure 42 – UPSA strategy diagram highlighting the interaction of torque reduction and torque recovery (shift shock adjustment) values during an up-shift phase. [27]

DNSA (Down Shift Assist) strategy can also be used to refine down shift phases without the need for clutch use. Within this strategy, the amount of throttle blip when down shifting can be adjusted, as well as the amount of engine braking that is introduced when down shifting and the gear is engaged. Both parameters within the software are labelled as Blip TH Adj. (Blip Throttle Adjust), and EB Adj. After Shifting (Engine brake adjust after shifting). Increasing Blip TH Adj. gives the motorcycle more of a throttle blip when down shifting, and decreasing the value gives the motorcycle less of a throttle blip. Increasing EB Adj. After Shifting gives weaker engine braking, and decreasing the value gives stronger engine braking. These parameters can be adjusted through each gear and for rpm sites from 5000rpm through to 15000 rpm.

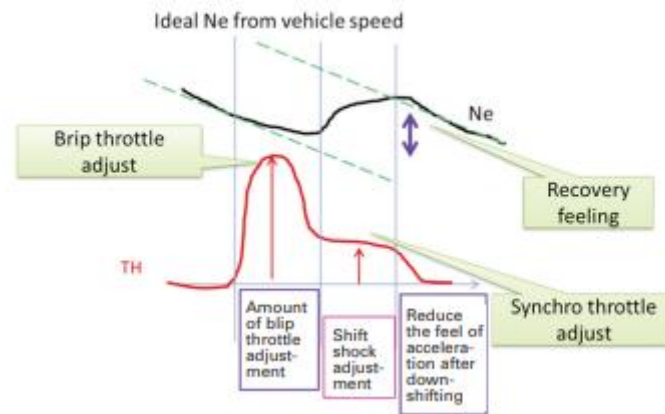


Figure 43 – DNSA system operation diagram highlighting how each of the adjustable parameters operate. [27]

Upwards and downwards shift voltage thresholds can also be set for each gear, which are used to control timing at which shift control begins. These voltage values represent the force that is required before the ECU would begin to introduce shift control strategies for either an up shift or a down shift. Lower voltage thresholds represent less force required before the control strategy becomes effective, and higher voltage thresholds require higher amounts of force through the shift lever before any shift control strategy will be implemented.

SFTAD UP THR. 1st - 2nd	3.26 (V)
SFTAD UP THR. 2nd - 3rd	3.26 (V)
SFTAD UP THR. 3rd - 4th	3.26 (V)
SFTAD UP THR. 4th - 5th	3.26 (V)
SFTAD UP THR. 5th - 6th	3.26 (V)
SFTAD DN THR. 2nd - 1st	1.88 (V)
SFTAD DN THR. 3rd - 2nd	1.88 (V)
SFTAD DN THR. 4th - 3rd	1.88 (V)
SFTAD DN THR. 5th - 4th	1.88 (V)
SFTAD DN THR. 6th - 5th	1.88 (V)

Figure 44 – Upwards and downwards shift threshold voltage parameters that can be used to alter force required for shifting control strategies to be implemented.

Within the HRC Data Setting Tool software, there are some Shift Control Selection values, which are used to determine shift related functions, and work based on either 0 (off), and 1 (on) inputs. Within this section, there are five different functions which all must be determined correctly for shifting and blip control strategies to work correctly. Functions listed include:

- Shift Control
- Upshift Control
- Downshift control
- SP Quick shift
- Upshift Input

Shift control(1:on,0:off)	1 (SW)
Upshift cont.(1:on,0:off)	1 (SW)
Dnshift cont.(1:on,0:off)	1 (SW)
SP Quickshift(1:on,0:off)	0 (SW)
Upshiftinginput(1:com,0:ten)	1 (SW)

Figure 45 – Shift Control Selection values within HRC Data Setting Tool software.

Following consultation with the HRC Data Setting Tool software manual [27], and after evaluating the pre-set parameters within the software, it became apparent that there were two possible causes as to why the quick shift and blip systems weren't working correctly at the Cookstown 100. Located on the top of the engine on the Honda CBR 1000 RR-R SP, there are three small switches which could have been installed in the wrong locations. The other possibility was that the shift control selection values, as shown in figure 45, were set wrong.

Two of the three switches were known as spindle switches, one which was specifically for up shifting, one which was for down shifting, and the third switch was a neutral switch. The purpose of these switches is to allow the ECU to recognise which gear it is in and recognise when the motorcycle is in neutral.



Figure 46 – Three spindle switches located on top of the engine, one for up shift, one for down shift, and one for recognising when the motorcycle is in neutral.

The most necessary cause of action for this issue was to begin with a process of elimination. By consulting the wiring diagram for the motorcycle, as found within the manual [27], it was possible to identify the three small switches and determine their locations and most importantly, identifying the coloured wires that each switch has and corresponding that with a location on the engine.

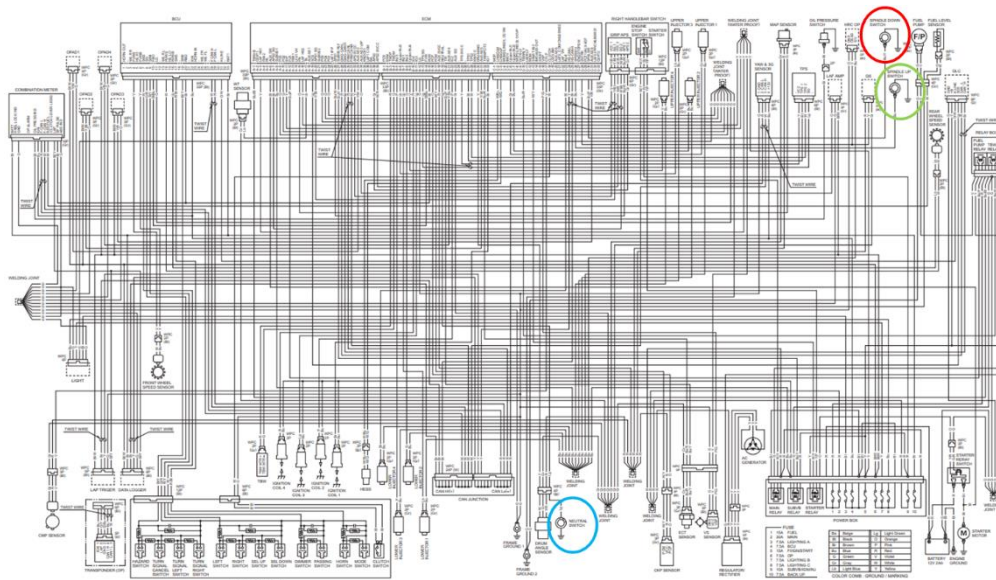


Figure 47 – Honda CBR 1000 RR-R SP wiring diagram, neutral switch (blue circle), up shift switch (green circle), and down shift switch (red circle). [27]

As figure 47 shows, each switch has different coloured wires that run to it. Following consultation of the wiring diagram, it was possible to identify each switch by the colours of wire that were going into it, this can be seen in figure 46. The wiring diagram showed that the neutral switch had a light green (Lg) wire, the upward shift switch had blue wiring (Bu), and the downward shift switch had blue and yellow wiring (Bu/Y).

After confirming that all the spindle switches were in their correct locations, that then allowed for that to be eliminated from the possible causes of the issue. This then meant that the only other possible cause was that the shift control selection parameters within the software had been inputted wrong. The process of testing and checking these values was conducted whilst the motorcycle was on a work bench, whilst the rear paddock stand held the rear wheel suspended above the ground.

Normally, motorcycle quick shifters and blip systems do not work if the front wheel is not travelling above certain speeds, which in this scenario it was not. Within the HRC software, it was possible to place the bike into chassis mode, which essentially allows the motorcycle to be used on a rolling road dyno, and in this case on a work bench, so that the shifter and blip settings could be checked efficiently.

To place the bike into chassis mode, the following steps should be followed:

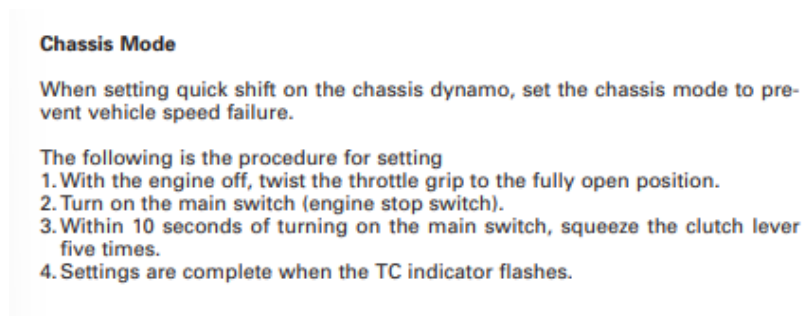


Figure 48 – Instructions on placing the motorcycle in chassis mode so tests could be carried out. [27]

So that the shift control selection values could be tested efficiently, it was the most logical process to change each value to the off position one by one and conduct a test on the bench whilst the bike was in chassis mode. By conducting these tests individually, it was possible to identify the point at which the dashboard started showing gear position correctly. If the dashboard continued to show the same problem, then the value was changed back to its original setting. By conducting these tests, eventually, a configuration was found where the bike started to work as it should, by showing a constant gear position on the dashboard, as well as the quick shift and down blip systems working perfectly whilst in chassis mode on the workbench.

4.2 Engine Issues

Following from the Cookstown 100 meeting, where it was possible to solve the quick shift and auto blip issues, focus then shifted towards the North West 200, which is a large event held each year and forms a major part of the team's calendar.

During the first day of practice/qualifying at the North West 200, the motorcycle suffered an engine failure. The damage was enough to force the team to withdraw the bike for the remainder of the meeting due to not having the required parts available to repair the engine at the race track.

When the bike was received back by the team, an initial diagnosis could take place. To do this, the generator cover was removed to allow the engine to be turned manually using a 17mm spanner, which would mean that any tight spots within the engine would become apparent whilst turning the crankshaft by hand. This was in fact the case and there were quite significant tight spots whilst turning the crankshaft.

Once it had been established that the engine had tight spots, which was a strong indicator that there was something significantly wrong internally, it was decided that the oil should be drained to check whether there was any debris within the oil. Upon draining the engine oil, which it is worth noting was brand new on the morning of the failure, it was apparent that there had been a conrod shell bearing failure, as there were flakes of bronze material within the engine oil, the same material that the conrod shell bearings are made from. At this stage, the next most logical step was to remove the sump, so that it could be examined to find how much shell bearing material there was and to gain an initial indication on how bad the engine failure was. Once the sump had been removed, there was a significant amount of bronze material still in there, which confirmed the fact that a conrod shell bearing had failed.



Figure 49 – Small fragments of bronze conrod shell bearing material that was found inside the sump of the engine.

Following some evaluation on what had occurred with the engine failure, and the scenario in which it had happened, which was at the end of a long straight section of circuit, where there was a long braking zone, it was believed that the cause of the engine failure was due to oil starvation, causing the conrod shell bearing to seize.

Oil starvation is one of the most common causes of conrod shell bearing failure, when there is no oil to lubricate the components adequately, this encourages metal to metal contact between components with no lubrication, which results in component damage. This is often seen when engines are run persistently with a low oil level. [28]

Where the engine failure occurred, the motorcycle had been held at 100% throttle for a sustained period, and then subjected to a long braking zone of around 400 yards. In this braking zone, due to load transfer of the motorcycle, mass is transferred to the front of the motorcycle causing the front suspension to compress. During this prolonged braking phase, the oil within the engine washes toward the front of the engine, due to the viscosity of the engine oil when it is hot. When the engine oil is hot, the viscosity drops, causing the oil to become very thin and more like water [29], which allows it to wash towards the front of the engine and leave the oil pickup dry during braking.

On the Honda CBR 1000 RR-R SP, the oil pickup is situated at the back of the sump, toward the rear wheel. This therefore meant that when the oil viscosity dropped and the motorcycle was braking for roughly 400 yards, oil was able to wash away completely out of the sump, causing the oil pickup to suck air rather than oil, causing metal on metal contact and ultimately causing engine failure.

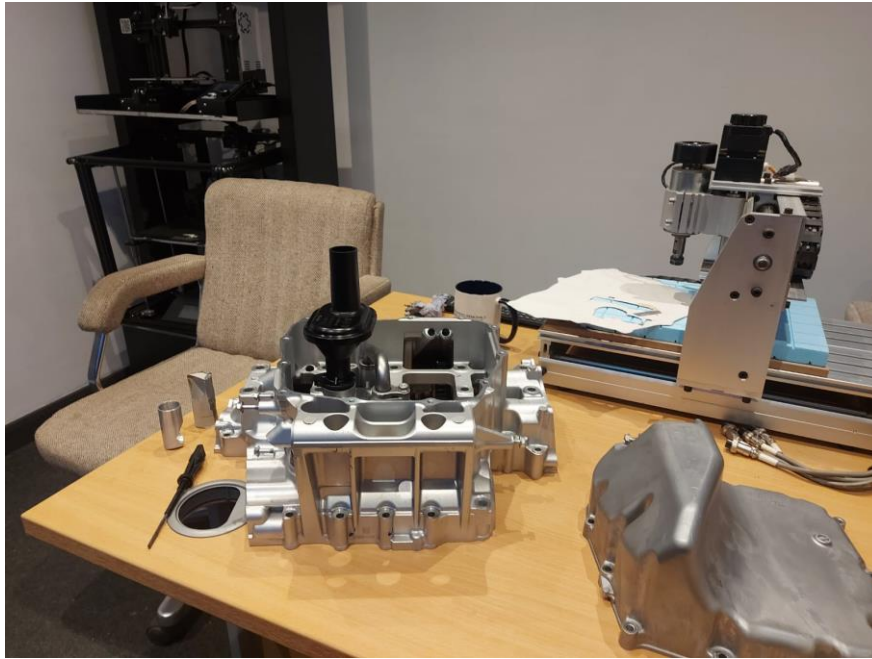


Figure 50 – Engine crank cases, with the sump removed revealing the location of the oil pickup.

Following a full strip down of the engine where all components were removed and checked, it became clear the full extent of the damage that was caused by the oil starvation. Due to the way in which the Honda CBR 1000 RR-R SP crankshaft oil ways are manufactured, conrods 2 and 3 receive their oil feed last. When the engine was stripped it was discovered that cylinder number 3 conrod shell bearing had picked up and rotated on the crankshaft journal, causing catastrophic damage to the conrod, crankshaft, and shell bearing.

This therefore meant that there was a significant list of components that needed to be replaced within the engine for it to be operational again. This list of components included a new crankshaft, connecting rods, connecting rod bolts, oil pump rotors, head gasket, and a full set of connecting rod shell bearings. It is also worth noting that there would only be a two-week period between the North West 200 and the Isle of Man TT which in that time the engine needed to be completely dismantled, cleaned, prepared, and rebuilt with all listed new components.



Figure 51 – Broken connecting rod, and crankshaft from the engine failure.

There was significant thought that went into how the oil starvation issue could be prevented from occurring again. There were three significant ideas which were all going to be tested to try and prevent future issues. It was suggested that simply running a higher volume of a thicker oil would go a long way to preventing future troubles, as well as developing a baffle plate that would sandwich in between the crankcases and the sump, to direct the oil into areas that are desirable and to prevent the wash that was experienced under heavy braking.

Initially, the oil that was in the engine at the time of the failure was a Motul 300V 2172H 0W-30 [30] which according to the technical data sheet made available by Motul, was specifically developed for maximum power and reliability. The oil was specifically developed by Motul and Honda Racing Corporation (HRC) .

PROPERTIES		
Color	Visual	Amber
Viscosity grade	SAE J 300	0W-30
Density at 20°C (68°F)	ASTM D1298	0.850
Viscosity at 40°C (104°F)	ASTM D445	50.7 mm ² /s
Viscosity at 100°C (212°F)	ASTM D445	9.5 mm ² /s
Viscosity Index	ASTM D2270	174.0

Figure 52 – Motul 300V 2172H 0W-30 oil properties.

As figure 52 shows, the oil viscosity drops significantly with higher temperatures, suggesting that a 0W-30 oil was too light of an oil to use for the bikes intended purpose. When looking at various engine oils and their grades, for example 0W-30, the 0 represents the lowest temperature that the oil will maintain its viscosity, and the 30 represents the suitability of the oil for higher temperature exposure. This means that a 0W-30 oil would hold its viscosity within the 30 degrees Celsius range. If the temperature of the oil was to exceed this, which in most scenarios it does quite considerably, then the oil would begin to thin and lose its viscosity. Once an engine oil begins to break down and lose its viscosity due to extreme temperature, then the oil loses its lubrication properties and would not provide enough lubrication to the internal engine components. [31]

A suitable way to monitor oil temperature within the engine in future would be to install an oil temperature sensor, which would allow for constant logging of the oil temperature as the motorcycle is running. Oil temperature carries far more significance than coolant temperature, which is shown on the dashboard of the bike.

It was felt that moving to a thicker oil, specifically Motul 300V² Factory Line 10W-50 would be a significant improvement. The oil was specifically developed for racing purposes using ESTER Core Technology and made up using a fully organic base by using non-fossil renewable materials. Motul claim that the oil provides increased power output, increased oil durability, and a more consistent level of performance from the engine.

PROPERTIES		
Color	Visual	Amber
Viscosity grade	SAE J 300	10W-50
Density at 20°C (68°F)	ASTM D1298	0.871
Viscosity at 40°C (104°F)	ASTM D445	107.5 mm ² /s
Viscosity at 100°C (212°F)	ASTM D445	17.7 mm ² /s
Viscosity Index	ASTM D2270	182.0
Pour point	ASTM D97	-36.0 °C / -32.8 °F
TBN	ASTM D2896	9.5 mg KOH/g

Figure 53 – Motul 300V² Factory Line 10W-50 oil properties.

When comparing the viscosity values shown in figure 53 to those shown in figure 52 for the 0W-30 oil, there is a clear improvement in viscosity when exposed to higher temperatures in the 10W-50 oil. Based on the information provided, it was a beneficial change to attempt to reduce the chance of engine failure due to oil starvation in future.

The quantity of oil being put into the bike was also given some consideration, with the decision being made that in future, more oil would be used within the bike. Justification for this decision came because under braking, the washing effect that has been described does not leave enough oil in the sump to always feed the pickup. Therefore, additional oil would ensure that even with the washing effect, there would always remain some oil around the pickup in the sump. This was another preventative measure, paired with the new oil grade as discussed, and the baffle plate development which will be discussed in following sub sections.

		CBR1000RR-R	CBR1000RR-R ST
Oil capacity	Upper level	4.0 liters	4.3 liters
	Lower level	3.5 liters	4.0 liters
	at oil change	2.8 liters	3.3 liters
	at filter change	3.0 liters	3.5 liters

Figure 54 – Recommended oil levels for the Honda CBR 1000 RR-R. [32]

As figure 54 shows recommended oil levels at different stages for both models of the Honda CBR 1000 RR-R, initially, prior to the engine failure at the North West 200, there was around 3.5L of oil in the bike, along with a new OEM oil filter. It was also discovered from another team also running Honda CBR 1000 RR-R bikes that it was advised to run around 0.5L more oil than what was specified on the manual. This advice was followed prior to the failure.

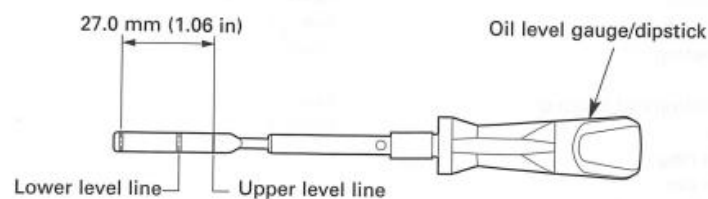


Figure 55 – Oil level dipstick markings as recommended by HRC within the manual. [32]

4.3 Sump Baffle Plate Development

So that the oil within the engine could be restricted in the ways it could wash and move under braking, it was decided that a baffle plate would be developed, that would be used as a sandwich between the crank cases and the sump, between two gaskets, which would also be made by the team.

The process began when the engine was completely dismantled, and there was easy access to all the components that would be required to design and prototype the baffle plate. Once all components had been washed and cleaned thoroughly using an industrial parts washing cabinet, the initial prototype phase began. This began with taking a series of measurements of the bottom face of the crank cases, specifically all the bolt holes which are where the sump mounting bolts locate. Once a

preliminary hand drawn design had been complete, a good friend of the team, Jeremy Goodall, who runs a machining shop was able to produce an accurate CAD drawing using Auto CAD [33] of how the baffle plate would be. The use of CAD allowed for accurate refinements and visualization of how the baffle would look. Unfortunately, those cad drawings are not available to the author of the project, due to not having access to all relevant software.

Using the CAD drawings produced by Jeremy, an initial prototype was laser cut out of a piece of thin plywood. This allowed an initial mock-up of the baffle plate, which showed that all bolt holes were in the correct places and that there were no issues with clearance.



Figure 56 – Prototype baffle plate primarily made for checking hole locations and that there was adequate clearance.

Once it had been confirmed that the prototype was successful, it was necessary to go ahead and have the first iteration produced out of stainless steel. Although not shown on the prototype in figure 56, there were some additional ‘slots’ that were machined into the baffle that would still allow the oil to move, however it would be much more restricted than with no baffle plate in there at all.

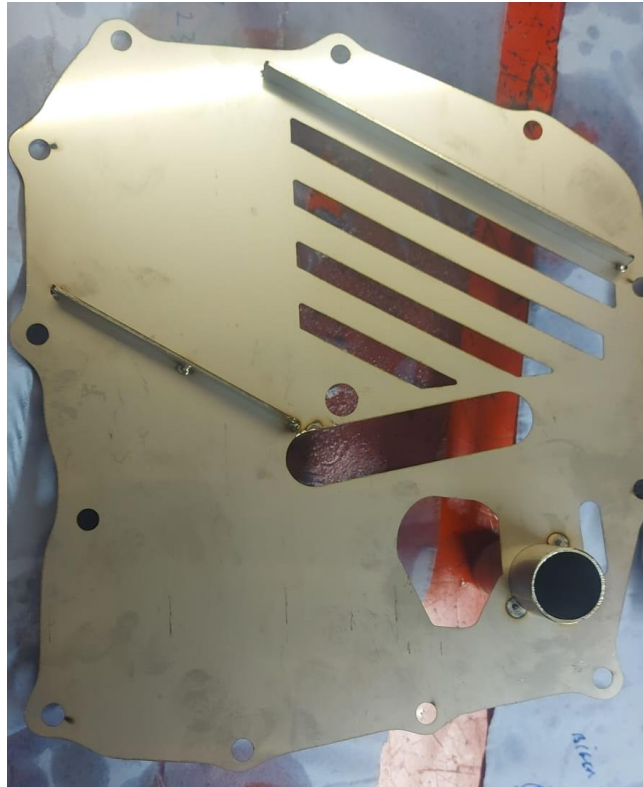


Figure 57 – Iteration number one of the baffle plate, complete with all oil ways, bolt holes and upright rails to direct oil efficiently.

Figure 57 shows the finished first iteration of the baffle plate. As mentioned previous, there are additional oil ways that were added into the design so that oil was still free to move without being totally restricted. There were also two rails that were welded onto the baffle plate, which would direct the oil back toward the oil ways and ensure that all oil was returning to its original location. Without these rails, oil would collect on top of the baffle plate, therefore reducing the volume of oil beneath the baffle plate in the sump which could eventually cause issues.

Using high grade gasket material, the team also replicated the OEM sump gasket, except made the gasket surface wider, which allowed the gaskets and the baffle plate to create more of a seal around the edge of the sump to prevent oil leaks. Using one gasket either side of the baffle plate also helped to create a strong seal.

To hold the baffle plate in place, one small M6 bolt was used to mount the baffle plate to one of the oil feed pipes, which are used to return oil back to the sump from the top of the engine whilst running. There were some slight issues whilst mounting the baffle plate for the first time. When the baffle plate was manufactured, and the rails were welded on, the baffle plate had become slightly distorted, which meant that the baffle plate did not sit totally flat on the surface of the crank cases. To remedy this issue, the baffle plate was placed on a flat plate, and a small hammer was used to

gently tap around the edge of the baffle plate to flatten any areas where there had been some distortion. After some flattening using the flat plate, the baffle plate was eventually flat enough so that it sat perfectly flat around the surface of the crank cases.

Once the baffle plate had been mounted to the engine during re-assembly, the engine could then be re-installed to the chassis, where it could then be run in again using the dyno. The engine was ran in using the same process as described previously, and by following the outlined procedure as found within the HRC manual.

**Break-in
MODE**

Engine rev (rpm)	Throttle grip opening	Time (min)
4,000	1/4	15
6,000	1/4	15
8,000	1/4	15
10,000	1/2	15

Use POWER MODE 1 of HRC PGM-FI setting tool or, if stock vehicle ECU, use P1 (see owner's manual).

Figure 58 – Engine recommended running in procedure, as recommended within the HRC manual. [32]

The rebuild, re-install, and running in procedure was completed with one day to go before the Isle of Man TT, which meant that there was no time for a shakedown test to be completed to ensure that there were no issues that would not present themselves whilst on the dyno. This meant that the first time the bike was used with the new engine and modifications, was in the first day of practice/qualifying at the TT.

4.4 Engine Failure No 2

Unfortunately, after completing only one day of practice at the Isle of Man TT, on the second practice day, the team suffered another engine failure, which occurred within the same conditions as the first engine failure. At the end of Sulby straight, which is around 1.5 miles long, and top speeds of around 200mph were reached at the 2023 event. At the end of the straight, there is a hard braking zone which is around 400-500 yards long depending on the approach speed, where riders would go from 6th gear down to 2nd gear. On his 2nd lap of the evening, as Julian was shifting down through the gearbox at the end of this 1.5 mile straight, the bike started making a concerning rattling noise, so to save any further detrimental damage, he retired the bike, and it was brought back to the paddock within a van for further inspection and diagnosis.

When the motorcycle arrived back to the team in the paddock, as before, the generator cover was removed so that the crankshaft could be turned manually using a spanner. As before, there were significant tight spots, which gave a clear indication that the same issue had occurred again. Since

the team were at the TT for two weeks, and this issue had occurred so early, there was a decision made that an attempt would be made to completely rebuild the engine there at the event.

When the engine was removed from the bike, the team engine builder had arrived on the island to begin the process of dismantling and rebuilding the engine. To ensure that the process was completed correctly and safely, a designated area was set out within the awning with a work bench and storage trays for all components so that nothing was lost or misplaced.

When the engine had been dismantled, it was confirmed again that the same problem had occurred as before, however the damage witnessed on the shell bearing, connecting rod, and crankshaft was not as bad as previous. This could have been due to several reasons, like if Julian managed to cut the engine in time before any more serious damage was caused, or that the engine oil that was being used offered in terms of lubrication, and the baffle plate ensured that there was oil in the correct places more of the time.

The main issue that was causing some concern within the team, was that even with the discussed modifications made to the engine, there was still an engine failure, which led the team to question what more could be done to ensure that the problem wouldn't occur again.

To arrange engine components that would be needed to rebuild the engine, parts were arranged same day by Honda UK, who are based in Louth, who managed to arrange all relevant components to be shipped directly to the race office at the Isle of Man TT paddock. This process took two working days to complete, which meant unfortunately the team would miss one evening of practice.

Fortunately, prior to the TT event, the team arranged for Julian's personal Honda CBR 1000-RR-R SP to be brought to the UK with the purpose of using it as a 'spare' bike that components could be taken from if needed. It was also arranged kindly by Gesslpower in Austria to have a new, 0 miles road bike that could also be taken to the Isle of Man, in case of any drastic emergency that required more components than what was attainable from Julian's bike.

When the broken engine was removed from the team bike, the process then began of removing the engine from Julian's personal bike so that it could be used in the team bike whilst the broken engine was being rebuilt. The use of another engine was appreciated by the team, however there was some concern over the condition of the engine that was being installed in the bike, as it already had around 1500km on it prior to installation on the team bike.

In normal scenarios, as specified by the team engine builder, race engines are only used for an absolute maximum of 1200km race miles before they should be removed, dismantled, and rebuilt using all new components. This to ensure that engine failures are kept to a minimum.

Before the loan engine was installed in the bike, the oil was drained and filter removed, and the sump was also removed, so that the baffle plate could be installed. It was also noted that the issue did not lie in the type of oil that was being used within the engines, as there had been two identical engine failures using two different grades of oil. The decision was made to change to Motul 300V 10W-40 oil. That decision was made due to vast availability, cost, and the team already used that oil on its Yamaha R6 machine, meaning that a large stock was already within the truck at the TT.

Based on the experiences and things learned from both engine failures, the team felt that the modifications made were largely a success, however it was felt that the only thing that could be done was to use even more oil in the engine, so that there would be always enough oil in the sump, regardless of how long the bike was braking for.

During rebuilding the bike, it was observed where the oil pump drive chain was in relation to the oil level, and how high the oil level could be before it began interfering with those moving components. When these observations were being made, it was noted that the oil could be brought as high as the dipstick hole, whilst still being low enough that it would not interfere with any other components.

There was some risk associated with adding even more oil, since there was already a substantial amount of oil being used initially, and adding more oil would take it to around 1L more than what was recommended by HRC. Running high amounts of oil causes increased oil pressure within the engine, which forces oil out of the engine commonly into the air intake system, this can cause engine damage, and causes the bike to burn excess oil. [34]

Motul 300V 10W-40 has been developed for a wide range of high-performance motorcycles. Motul claim that the oil achieves 1.3% horsepower gain whilst still offering maximum lubrication to all components. The technical data sheet also states that the oil offers outstanding gearbox protection, and that the oil can maintain stable pressure irrelevant of its running conditions. [35]

PROPERTIES		
Color	Visual	Yellow / Green Fluo
Viscosity grade	SAE J 300	10W-40
Density at 20°C (68°F)	ASTM D1298	0.852
Viscosity at 40°C (104°F)	ASTM D445	82.1 mm ² /s
Viscosity at 100°C (212°F)	ASTM D445	13.1 mm ² /s
Viscosity Index	ASTM D2270	160.0
Pour point	ASTM D97	-36.0 °C / -33.0 °F
TBN	ASTM D2896	8.3 mg KOH/g
Flash point	ASTM D92	250.0 °C / 482.0 °F

Figure 59 – Motul 300V Factory Line 10W-40 oil properties.

Comparing technical properties of the 10W-50 oil, and the 10W-40 oil that was going to be used going forward from the second engine failure, it becomes clear that the 10W-50 oil offers better viscosity values at high temperatures. At 100°C, the 10W-50 oil has a viscosity of 17.7mm²/s, whereas the 10W-40 oil has a viscosity of 13.1mm²/s. If cost and availability were not factored into the decision, then it would have been a better decision to continue using the 10W-50, however as mentioned, cost and availability reinforced the decision to move forward using 10W-40.

When filling the engine with oil, markings on the dipstick were ignored, and the engine was filled with oil until it became visible in the dipstick hole. Once the engine had been run in using the paddock dyno provided by Dynojet UK and it was confirmed there were no issues, the fuel tank was removed so that the airbox could be opened to check that it was dry, and that the engine wasn't rejecting any of the oil that had been put in. Initial signs were positive that this time the issue had been solved as there were no issues whilst on the dyno, and the airbox remained perfectly dry for the remainder of the TT.

Following all of the issues discussed, and both engine failures, the bike finished the Isle of Man TT with three out of four race finishes (DNF non machinery related), and achieved a best lap of 128.60mph, which makes the bike now the fastest machine that WH Racing Team have ever had around the Isle of Man TT course, and Julian was recognised as officially being the fastest ever mainland European rider. These were both significant achievements for both the team and Julian, and it was deemed as a great reward for the hard work and effort that everyone had put in to ensure that the bike was repaired and ran perfectly as much as possible. More reflection on the project can be found at the end of this report.

5 Electronics and Strategy Development

Since section three of this report has already identified the electronics and data logging packages that the bike was equipped with, the purpose of this section is to thoroughly explain electronic control systems that the bike has, how they are implemented, what controls them, and how their strategies have been developed since the project began. Since the Honda is equipped with so many different controllable parameters within the HRC Data Setting Tool software, only some of them have been tested, however over time as the project progresses into the future, all available strategies will be tested and used if beneficial, so they will all be included within this section of the report.

The introduction of electronic control systems for motorcycles marked their debut with Anti-lock Braking (ABS) in 1988 and Traction Control (TC) in 1992. Initially, these systems didn't provide great performance. It wasn't until the late 2000s, when racing teams demonstrated the significance of TC systems, that they gained wider use. [36]

ABS systems normally aren't permitted or aren't utilized in racing contexts. The Federation Internationale de Motocyclisme (FIM), the organising body of MotoGP banned the use of ABS, stating in [37] that 'Braking inputs must be powered and controlled solely by the rider's manual inputs.' Therefore, ABS will not be discussed within this section of the report.

Electronic control systems have often started in racing and then made their way into factory-made sports motorcycles. within this section of the report, the following systems and strategies will be discussed:

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

Within this section of the report, when describing the control systems and their strategies, some snips, and figures from software other than the HRC Data Setting Tool may be used as they may be clearer to explain and offer better visualisation of how the systems work.

5.1 Traction Control

TC systems play a crucial role in optimizing performance, primarily 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,' applies here [38].

In this situation, as the motorcycle accelerates, it generates a longitudinal force between the road surface and the rear tyre contact patch. This force compresses the front portion of the contact patch due to driving torque. As a result, this new force generates traction between the tyre and the road surface, creating forward stress. As the rear wheel continues to rotate, this stress reverses, causing the tyre to return to its original shape and size. During this phase, slip occurs when the tire slides on the road surface. [39]

Back in 2011, Kawasaki introduced their initial version of S-KTRC (Sport-Kawasaki Traction Control) a system designed to enhance maximum acceleration when exiting corners while riding. This system works on key factors such as front and rear wheel speed (slip), engine RPM, throttle position, and acceleration. [40], [41]

Slip

Slip represents as 'The difference in rotation between the front and rear wheels.' [13] This is typically measured in percentage but can also be represented as a ratio, referred to as 'Slip Ratio.' Among all the factors monitored by TC systems, slip stands out as the most crucial one. If the slip value exceeds a 'predefined relatively higher threshold' set in the ECU, the TC system intervenes to reduce the slip level to a value that the tyre can manage. [40]

The older TC systems, such as the one mentioned earlier, Kawasaki S-KTRC, consider only specific parameters. In contrast, modern, highly developed systems incorporate lean angle, also known as bank angle, to precisely determine the maximum force that can be applied through the rear wheel without causing excessive slip whilst exiting a corner. [13]

Considering lean angle in TC systems is important because there's a noticeable alteration in tyre circumference when the motorcycle is subjected to lean angle. This change in circumference directly impacts the allowable slip amount due to the tyres permissible grip capabilities whilst at lean angle. [13], [42]

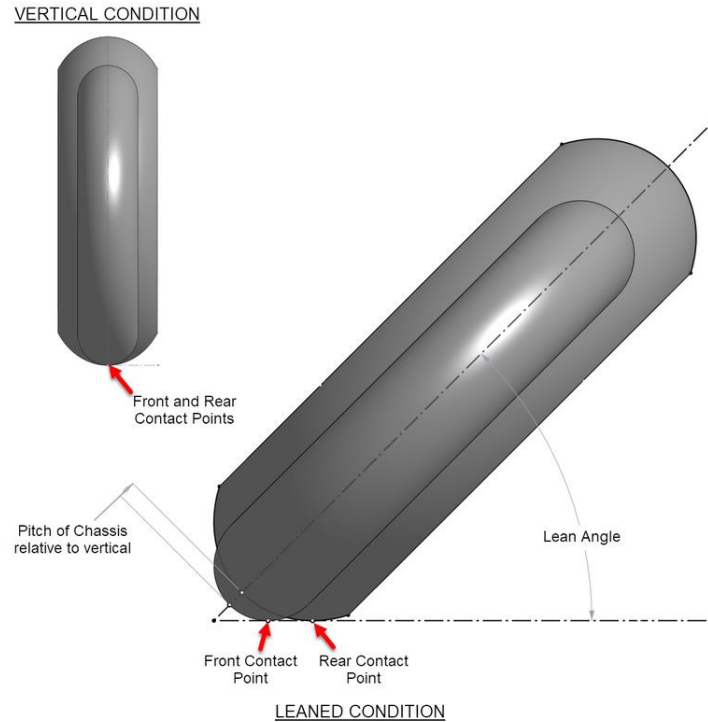


Figure 60 – Effect that lean angle has on the contact patch of a tyre. [43]

Commonly, modern ECUs like the one used in the kit HRC electronics package rely on both wheels having contact with the ground for TC systems to work, this commonly is not possible on the roads due to the nature of the circuit, and the number of jumps and crests that there are. For this reason, TC was not utilized throughout the project.

5.2 Engine Braking

Slowing down a motorcycle at very high speeds requires a significant application of braking force. This is where Engine Braking (EB) systems play a pivotal role. EB systems monitor information from electronic sensors and the calculations performed by the ECU and Inertial Measurement Unit (IMU) to regulate the engine's braking contribution. This collaborative effort of EB, alongside the normal braking system, aids in decelerating the motorcycle effectively. In the context of competitive racing, achieving the most efficient braking performance is imperative to securing a fast lap time.

EB systems function by adjusting the position of the throttle butterfly. In a conventional setup, when a rider releases the throttle, the throttle butterfly would typically shut completely. This action results in a very strong engine braking effect and reduces cylinder pressure since no additional fuel/air mixture is introduced into the cylinder [44]. EB systems are also controlled by cutting the cylinders of fuel, effectively stopping the combustion process, and thereby reducing the engine's rotational speed [45].

Shown below, an accurate demonstration of the introduction of EB systems during a MotoGP race. The figure was taken from data analysis software from a session at Circuito de Jerez [46], specifically capturing the moments leading up to Turn 5, known as Sito Pons corner. It vividly depicts the rider's throttle closure as they approach the corner, marking the instant when the rider initiates braking and downshifts into third gear. These preparatory actions engage the engine's brake mode.

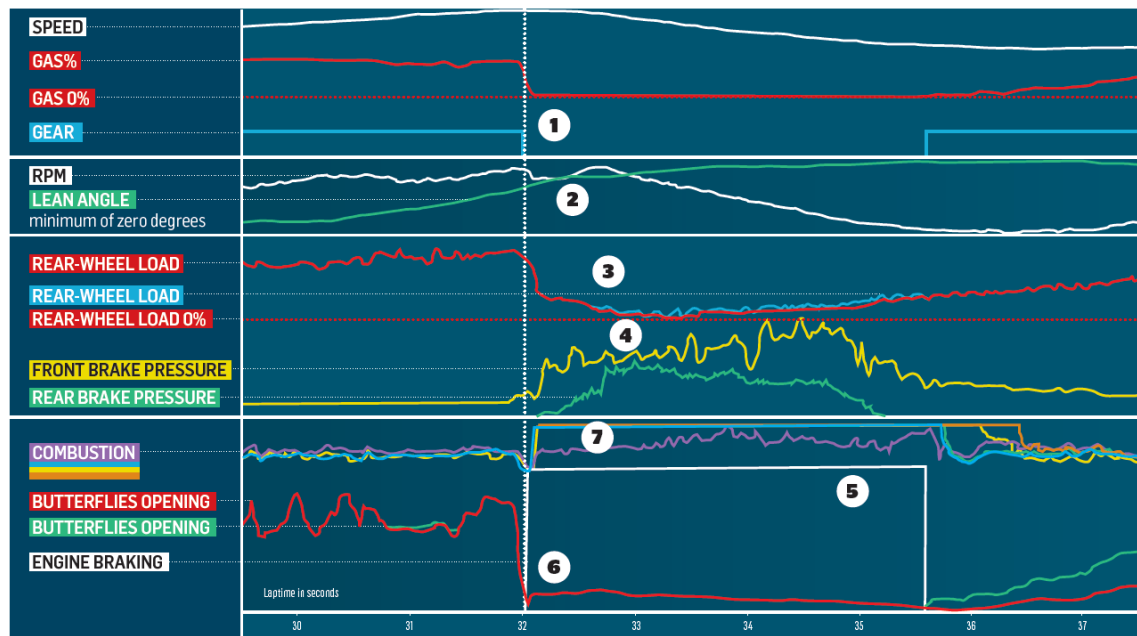


Figure 61 – EB systems being used within a racing context, using an example data trace from Circuito de Jerez. [45]

During the Isle of Man TT, the engine braking strategy was worked on extensively, based on feedback from Julian that stipulated that he felt there was too much engine braking, especially in gears 2-6. Based on this information, the engine brake strategy was significantly reduced over the fortnight, ending with a strategy that had almost 0 engine brake through gears 2-6. Within the HRC Data Setting Tool software, there are three settings that can be adjusted to influence engine braking. EB Mode, EB Skid Mode, and EB TH Min.

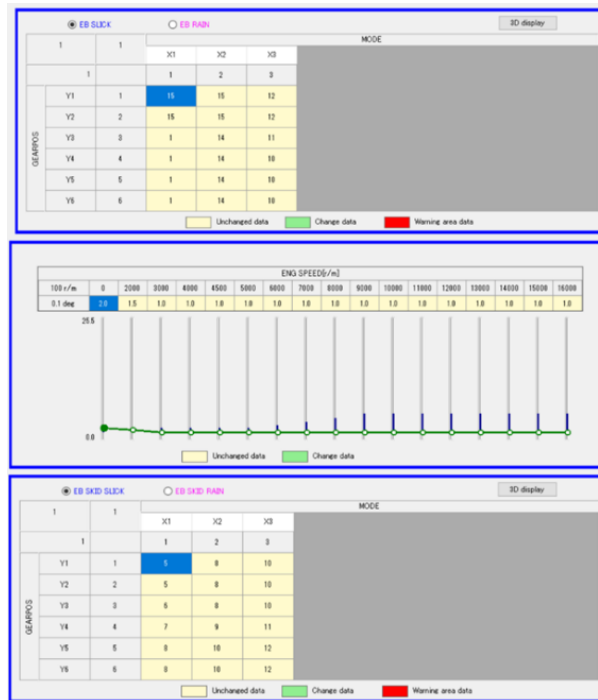


Figure 62 – EB Mode (top), EB TH Min (middle), and EB Skid Mode (bottom) within the HRC Data Setting Tool.

Primarily, EB Mode parameters were changed, as using that setting it was possible to adjust engine brake severity for each gear, across three modes that could be changed through the dashboard whilst Julian was riding. Since the Isle of Man TT is such a long lap (around 17 minutes) it was not possible to constantly return to the pit to make changes like it would be at a short circuit event, where a lap may only be 2 minutes long. Commonly modes 1 and 2 were different to each other, so that Julian could try mode 2 whilst out on a lap which reduced the chances of a wasted practice lap with a setting he did not feel comfortable with.

A reduction in values in EB Mode made the EB strategy weaker, therefore giving that specific gear less engine braking, whereas increasing the value made the EB strategy stronger and more aggressive. As the top of figure 62 shows, gears 2-6 were running significantly weaker EB when compared with modes two and three which were still using standard values.

EB TH Min can be altered to change the amount of throttle butterfly opening that there is when the throttle is fully closed. Changing the amount that the throttle butterfly is open by adjusts the degree of engine brake (back torque) [27]. When the throttle grip is twisted from fully closed, the amount of throttle opening changes smoothly to the amount calculated in relation to the power mode that the motorcycle is in from what is set for when the throttle grip is totally closed. EB TH Min can be adjusted from 0rpm through to 15000rpm.

Adapting EB TH Min can also be helpful when trying to implement EB in a smooth manner without too much intrusion, it can be used to blend between throttle opening and EB introduction whilst entering a corner. Without this setting, EB could feel very intrusive and abrupt when the throttle is closed, causing a lack of confidence and performance whilst entering corners.

EB Skid Mode can also be used in a very helpful way. EB Skid Mode allows the user to adjust the amount of throttle butterfly opening when rear wheel deceleration is too excessive in relation to front wheel speed, which often causes skids due to back torque during deceleration. Using EB Skid Mode allows for smooth deceleration whilst ensuring that the rate of rear wheel deceleration remains controlled without skids, whilst also being as aggressive as possible.

5.3 Anti Wheelie

Anti-Wheelie (AW) systems represent an essential electronic control system that has seen extensive inclusion in the motorcycle industry in recent times. These AW systems play an important role in enhancing stability during rapid acceleration and surges in throttle input. As riders exit corners and demand significant throttle input, this generates substantial acceleration forces. During this acceleration phase, weight shifts to the rear, which causes a situation where the front suspension unloads entirely. Consequently, the front of the motorcycle becomes significantly lighter, which therefore increases the chance of a wheelie significantly. [47]

The purpose of AW systems is to maintain front wheel contact with the ground as much as possible. AW systems can be deployed using various approaches. In a 2018 paper published by Suzuki Motor Corporation [48], the advancement of AW control using two distinct methods are discussed, dependant on the detection of front wheel lift (wheelie).

One of the methods utilized an open loop system based on a vehicle dynamics model, which was used to control the amount of driving force delivered to the rider based on request. Alternatively, another method used a closed loop model which was constructed using a combination of a vehicle dynamics model, an Inertial Measurement Unit (IMU), and a three-axis gyroscope which was used to obtain angular measurements. [48]

Both methods were implemented so that there would be a continual feedback loop to the ECU, which allowed for greater refinement on the AW strategy. This ensured that the ECU was able to always deliver maximum possible driving force.

Anti-Wheelie (AW) systems consider variables such as RPM, the position of the front suspension, pitch, and the selected gear to predict a wheelie. The systems respond by adjusting the throttle, either partially or fully closing one or more throttle bodies, which therefore reduces the power and

torque supplied to the engine. This operation is comparable with systems discussed previous like traction control systems. The following figure illustrates a scenario where the AW system becomes active, as a MotoGP rider accelerates out of Sito Pons corner (turn 5) at Circuito de Jerez. [46]

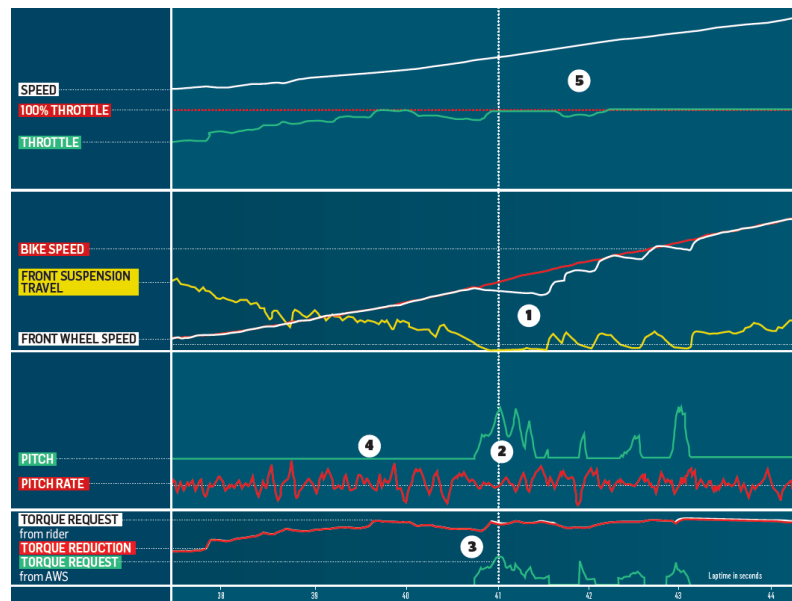


Figure 63 – Example of an AW system being utilized during corner exit. Shown through a data trace at Jerez turn 5. [49]

Like previously mentioned within the traction control section, on the Honda CBR 1000 RR-R at road racing events, Anti-wheelie was not used extensively due to the nature of the circuits containing lots of jumps and elevation changes, which make it difficult for AW systems to be used effectively. Within the HRC Data Setting Tool software, anti-wheelie can be adjusted per gear across three modes that can be switched between whilst the bike is running. ‘Wheelie Mode’ can be used to change the intrusion level within a range of 0 to 15, where 15 is maximum wheelie control, and 0 is no wheelie control at all. It is also worth noting that it was possible to define settings for rain modes also, however the bike was not used in wet conditions throughout the project duration.

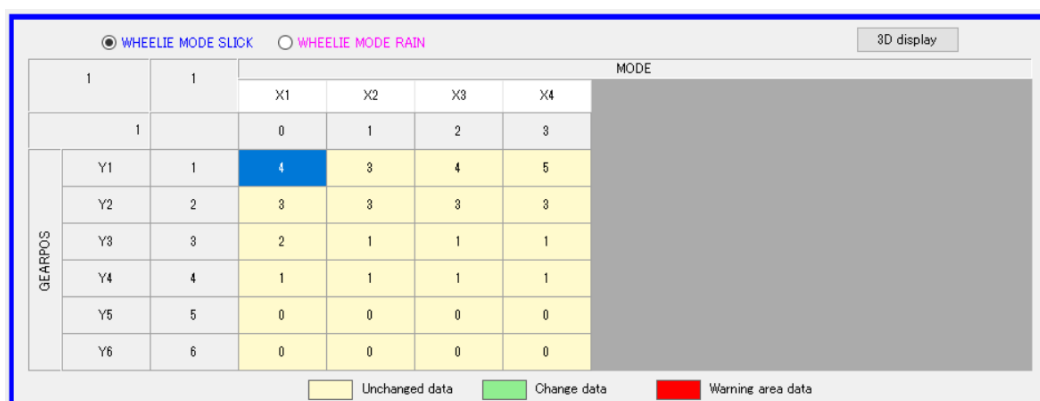


Figure 64 – Wheelie Mode parameters within HRC Data Setting Tool software.

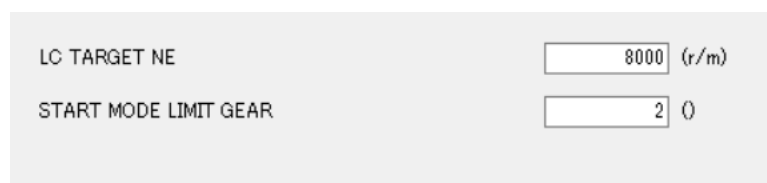
As figure 64 shows, low levels of anti-wheelie were used throughout the project, with a maximum parameter of 4, the bike was allowed to wheelie so that Julian could control wheelie manually using throttle control and by operating the thumb brake. This ensured that there would be no issues with anti-wheelie being introduced when it was not wanted.

5.4 Launch Control

Launch control systems are designed to facilitate rapid acceleration from a standstill, enabling both the rider and the motorcycle to accelerate at a fast rate without concerns of the front wheel lifting or the bike losing control due to excessive wheel spin. These systems ensure that the motorcycle transitions from a stationary position quickly and efficiently.

When launch control mode is engaged, the rider can maintain 100% throttle opening while keeping the clutch engaged. Then, by swiftly releasing the clutch, the Electronic Control Unit (ECU) intervenes to regulate the power sent to the engine. This ensures that acceleration occurs as swiftly as possible while maintaining smooth and, most importantly, safe operation.

The 'Start Mode' on the Honda works based on two given inputs, 'LC TARGET NE' which is the rpm limit that the ECU will maintain whilst start mode is engaged. 'START MODE LIMIT GEAR' is the gear at which when engaged, start mode will automatically disengage. Normally, this input is set to 2nd gear. When the clutch is released, engine power output is gradually returned from output restricted by start mode to ordinary power output based on throttle grip position that the rider is requesting. [27]



The image shows a screenshot of the HRC Data Setting Tool software interface. It features two rows of settings. The first row is labeled 'LC TARGET NE' and has a text input field containing the value '8000' followed by the unit '(r/m)'. The second row is labeled 'START MODE LIMIT GEAR' and has a text input field containing the value '2' followed by a gear icon.

LC TARGET NE	8000 (r/m)
START MODE LIMIT GEAR	2 ()

Figure 65 – Start mode parameters within HRC Data Setting Tool software.

Unfortunately, after completing some testing on a small private road, it was discovered that the start mode didn't perform as expected. Various setting configurations were tried, and multiple test starts were completed, however it was decided at the end of the test that start mode would not be utilized going forward. It was hoped that the HRC kit electronics package would receive an update in future to improve the performance and overall consistency of the start mode system.

5.5 Throttle Mapping / Ride by Wire

In the past, motorcycles were conventionally fitted with mechanical throttle systems that used physical cables connecting the throttle on the handlebar to the throttle body. These mechanical systems had a long-standing history until manufacturers started to innovate with electronically controlled throttle systems, often referred to as Ride by Wire (RBW). On some modern motorcycles, there are also systems that utilise both a cable and an electronic sensor like what will be discussed within this section of the report.

RBW (Ride by Wire) throttle systems are constructed using sensors responsible for transmitting data to the ECU (Electronic Control Unit) and actuators that receive instructions from the ECU to manipulate the throttle butterfly's opening and closing. In RBW systems, the management of air intake flow is achieved through an electronic device that works in place of the conventional mechanical throttle valve. While throttle butterflies are still used, RBW systems electronically regulate them through a motor. Throttle position sensors play a crucial role in regulating the angle at which the throttle butterfly is opened. [50]

Yamaha developed the first RBW throttle system on their YZF-R6 in 2006. The Yamaha RBW system, known as the Yamaha Chip Controlled Throttle (YCC-T) incorporated a compact 32-bit Central Processing Unit (CPU) responsible for managing each of the four throttle valves, one for each cylinder. This setup conducted calculations based on input data every 1000th of a second, allowing the system to maintain precise control over rider input and subsequently deliver highly detailed mapping adjustments. [51]

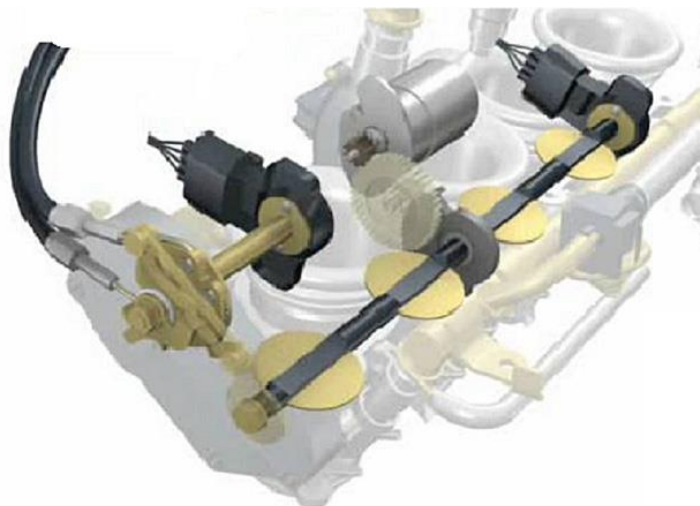


Figure 66 – Yamaha YCC-T RBW throttle system. [51]

Using the HRC Data Setting Tool software, throttle settings can be adjusted through 'Power Mode', or through 'TH GRIP ADJ.' (Throttle Grip Adjust). When changing power mode, the degree of throttle valve opening is changed dependant on engine speed, and throttle grip position for each power level which is chosen by 'TBW' (Throttle by Wire) function. Within the software, there are three power settings which can be chosen (aggressive, smooth, and mild). Within each of those three power settings, there are five different possible variations for each of them. Values from 1-5 are considered aggressive, 6-10 are standard, and 11-15 are mild.

	POWER MODE		
	Aggressive	Standard	Mild
FULL POWER	MODE 1	MODE 6	MODE 11
↕	MODE 2	MODE 7	MODE 12
	MODE 3	MODE 8	MODE 13
	MODE 4	MODE 9	MODE 14
LESS POWER	MODE 5	MODE 10	MODE 15

Figure 67 – Power mode types and variants within the HRC kit electronics package. [27]

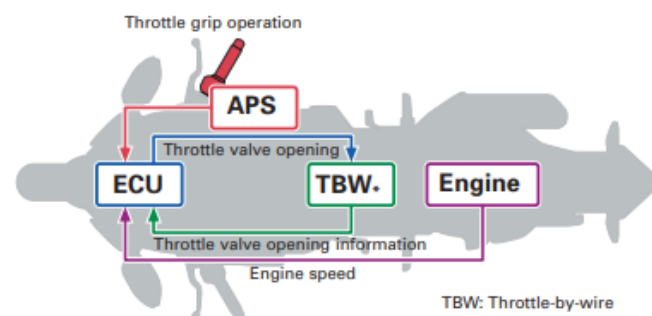


Figure 68 – Honda Throttle by Wire (TBW) system operation diagram. [27]

Commonly, using modes 11 to 15 would be beneficial to make initial throttle openings subtle, which would be beneficial for low-speed corners. Using modes 1 to 5 make the system much more aggressive. During the Isle of Man TT, Julian made some comments that the bike was hard to ride and was requiring a lot of physical input from him. Since anti-wheelie use was kept to a minimum, some adaptations were made to the power mode to make the bike gentler in lower gears, this was achieved by using characters 7-10 whilst in 'standard' power mode. Those characters are defined as 'Less Power Modes' which are most impactful in first and second gears which make throttle opening easier [27]. It is also worth noting that each of these characteristics can be altered for each gear.

6 Conclusion

At the beginning of this report, aims and objectives were identified that would provide the motivation and identity of the project. It was the goal to construct and run a Honda CBR 1000-RR-R SP that would be used throughout the 2023 season.

It is felt by the author that most of those goals have been met. It is felt that overall, a highly competitive motorcycle has been constructed and set up to a standard that ensured that the bike can be used at all the intended events and be capable of achieving high level results. It was also intended that a fair and non-bias opinion would be provided throughout the report, and that has been given to the best of the authors ability.

Majorly, the project has been considered a success, however there was a significant number of problems that were encountered throughout the project, which have been covered in good detail including mitigation procedures and changes that were made to prevent the same issues from occurring again. Unfortunately, engine failure occurred on two separate occasions, both from the same issue, which it was felt that was significant bad luck. Even with these failures, extensive amounts of work were completed so that Julian and the team did not miss more than one day of practice at the Isle of Man TT.

Another significant mark of success for the project is the fact that the bike was used in four races at the Isle of Man TT, (2x Superstock and 2x Superbike) and three race finishes were achieved. Superstock race two was not finished due to Julian retiring on personal grounds. This therefore proved that the bike had been built to a standard that not only was fast and competitive but was safe and durable. That is often a more important aspect when racing at the Isle of Man TT.

The team and Julian left the Isle of Man TT with some respectable results, and a fastest lap of 128.60mph, which made Julian the fastest ever non-English speaking rider at the TT. This was a very rewarding aspect of the project and made the work and hardships worthwhile.

In terms of future works, it would not be fair to state that there are no areas to improve on. There are definitive areas of the project that if there was more time, then the outcome could have been even better. It is the opinion of the author that if there was more time to complete testing prior to the events, then electronic strategies could have been further developed which could have made the bike more useable for Julian.

Looking to the future, beyond submission of this report, the team will be taking the bike to the Macau GP, where the circuit is much more like a short circuit compared to a road race like the Isle of Man TT. This event is greatly anticipated by the author as there will be great opportunities to develop the electronics set up of the motorcycle to suit the circuit, and to try different configurations that have not been tried previous.

Overall, the project has been deemed as a success, and it is felt that all goals and objectives have been met to a satisfactory degree.

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