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A NEW TEST RIG FOR MOTORCYCLE RIDER IMPEDANCE MEASUREMENT

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Abstract

There are many factors affecting motorcycle stability, with the rider remaining a significant unknown. Here we show the University of Southampton's motorcycle shaker rig, a new piece of equipment to take rider impedance measurements. This rig improves on previous investigations, by taking 10 force and moment measurements, as well as using up to six IMUs. This new rig also allows the effect of posture to be investigated for the first time. As posture has a significant effect on human response to vibration, and there is a large difference in posture between motorcycle styles, this a key investigation for motorcycle stability. The rig's overall design is presented first, then a closer look at the ergonomics, and an explanation of the instrumentation system. Finally, preliminary results are presented, to show the capabilities of this rig and instrumentation system.

Introduction

Motorcycle stability varies with many factors, and the effect of machine geometry, part mass and frame stiffness can be readily calculated using numerical methods. However, the rider needs an empirical model, built from measured data on the riders response to vibration. Whilst a few papers have shown that the rider influences stability (e.g. [9]), there is still no validated model that predicts how different riders will affect stability. The passive effect is most interesting, as the least stable modes, weave and wobble, usually occur above the frequency of human control [10].

Further investigations need to be made, looking for better ways of representing the rider, as a mass spring damper system. These models represent the rider as predominant masses, such as the legs, and one or two portions for the upper body. These masses are connected to one another, and the motorcycle, using joints and springs. Figure 1 shows an example with masses for the legs and the upper body. These masses are connected to the motorcycle frame, and handlebars, using spring dampers y & a. The rider's upper body can roll and yaw relative to the lower, using joints which are constrained by two other springs. This type of model is commonly used to represent the rider in motorcycle stability investigations.

To build more comprehensive models, more human response data is needed. Currently studies have looked at roll and steering in isolation, with little attention to connections between motions of one body, and forces on another (e.g. connection between upper body roll and steering torque). An understanding of the connection between height, weight, posture and the rider's response is also required, to create a truly useful model. More measurements are required, to allow the rider's movement, and interaction with the motorcycle, to be studied more closely.

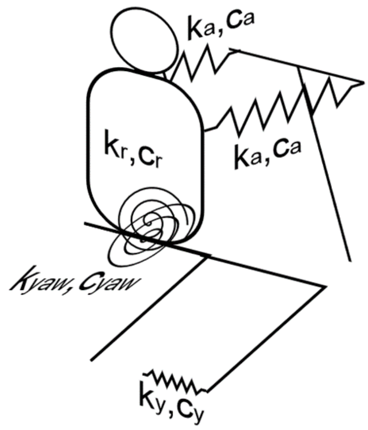


Figure 1: Example of the rider as a mass spring damper system, with legs and torso masses. springs connect body parts to each other, and the motorcycle. Similar to [1]

This paper presents a new motorcycle test rig, which allows for greater measurement of the rider's response to vibration. Better passive rider models will be created from this data, which can be used in motorcycle design to ensure new motorcycles are stable, regardless of the rider. The overall design is presented first, then a closer look at the ergonomics and an explanation of the instrumentation system used on this rig. Finally, preliminary results are presented, to show the capabilities of this rig and instrumentation system.

Concept and Design

Requirements

To ensure the rig would be useful in exploring rider impedance, a list of requirements was created. It was determined that the rig must do the following things:

- represent key motions from motorcycle stability modes
- be light enough to have all motions driven by one hydraulic shaker
- be stiff and strong enough to resist the driving forces, and support normal riders, with minimal flex
- have ergonomics that represent real motorcycles
- provide useful measurements for rider impedance investigations

Following consideration of these points, it was decided roll, yaw, steering and lateral movement should be represented if possible, as these are the key components of weave and wobble. To allow for all three rotations, a gimbal setup was selected, which can be mounted on a vibrating platform to replicate lateral motion. Space frames were used where possible, due to their high strength and low weight. The control locations were to be selected by measuring real motorcycles. A new measurement system is to be used, which includes force sensors integrated into the rig. The following sections explain each of these key points in more detail.

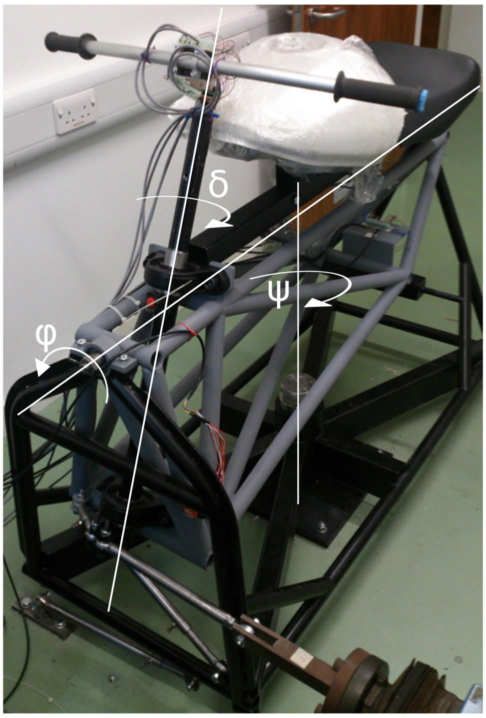


Figure 2: Motorcycle shaker rig, with axes of rotation highlighted for yaw(ψ), roll(ϕ) and steering (δ)

Structure

The gimbal setup for this rig had to allow the rider to experience roll, yaw and steering motions, as if they were on a real motorcycle. A bearing connects the yaw frame to the floor, with the roll frame suspended within. The steering column is mounted to the roll frame, and can rotate about its own axis, as shown in Figure 2. The yaw frame had to use a flat design, so that the roll frame can swing within it. The roll frame has the seat, tank, and footpegs mounted to it via load cells, and uses a tubular space frame design, to minimise flex and weight.

To allow these three rotations to be driven by one shaker, the frames can be locked together. Sliding rods are placed between the steering column, roll frame, yaw frame, and ground. To drive a given motion, three of the rods must be locked, to prevent relative motion, and one left to slide. For example, to drive yaw, all rods are locked, except the rod connecting the yaw frame to the ground. This method transfers the shaker's force to the desired frame, whilst other frames react on the ground.

The location of the movement axes was important, as the ratio of rotational to lateral motion should match a motorcycle in weave and wobble. Differences here would make the rig feel unnatural, and would affect rider response. The steering axis is along the centre of the steering column, which matches real motorcycles, as the handlebar is mounted with a forward offset. The roll and yaw axes were more difficult to locate.

The yaw axis location is not discussed in the previous study of rider yaw response [11], nor in motorcycle simulator design papers. The yaw axis was put though the centre of the rig, as a motorcycle will yaw about it's centre of mass, which is in the same location, relative to the rider, on the rig. Locating the axis here also improves stability and reduces driving forces for the rig.

The roll axis was the most difficult to locate, as there is little agreement amongst

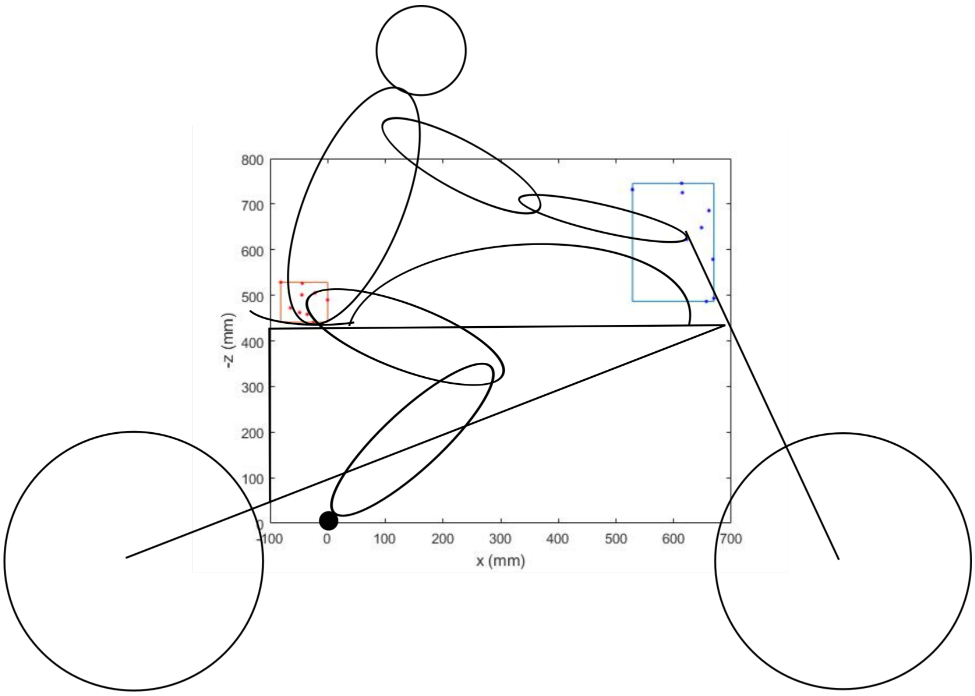


Figure 3: Location and distribution of handlebar and seat locations, relative to the foot pegs, for nine supersport and touring motorcycles

current literature. The roll axis is placed at the ground in [2] & [3], to more accurately represent motorcycle capsize, whilst some simulators place the roll axis at the riders head [4], to better simulate the rider's control method. As passive response has little effect on capsize, and the rider doesn't control instability, the roll axis was made to intersect the motorcycle's centre of gravity. This is thought to best represent the weave scenario (observed in [7]), agrees with [5], and minimises driving forces for the rig.

Ergonomics

The importance of posture to vibration response is shown in [6], as such the rider's posture on the rig, must match real motorcycles as closely as possible. The rider's position on a motorcycle is defined by three components, the footpegs, seat, and handlebars. To ensure a good match between the rig and real world, nine supersport and touring motorcycles were analysed. Figure 3 shows the results of this investigation, SAE coordinates (x forward, y right, z down) are used with the origin located at the footpeg.

The most significant result from this investigation, is that seat to handlebar height (Z distance) varies by 221mm. This variation shows a significant difference in posture between supersport and touring motorcycles, with the rider leaning much further forward on a supersport motorcycle. To represent these two extremes, an adjustable steering column was designed, which can be locked in either position. This allows the upper body position to be correct for ether situation, but has no effect on the lower body. For this rig the footpegs are fixed in a median position, as the legs are thought to have a limited effect, when compared to the upper body.

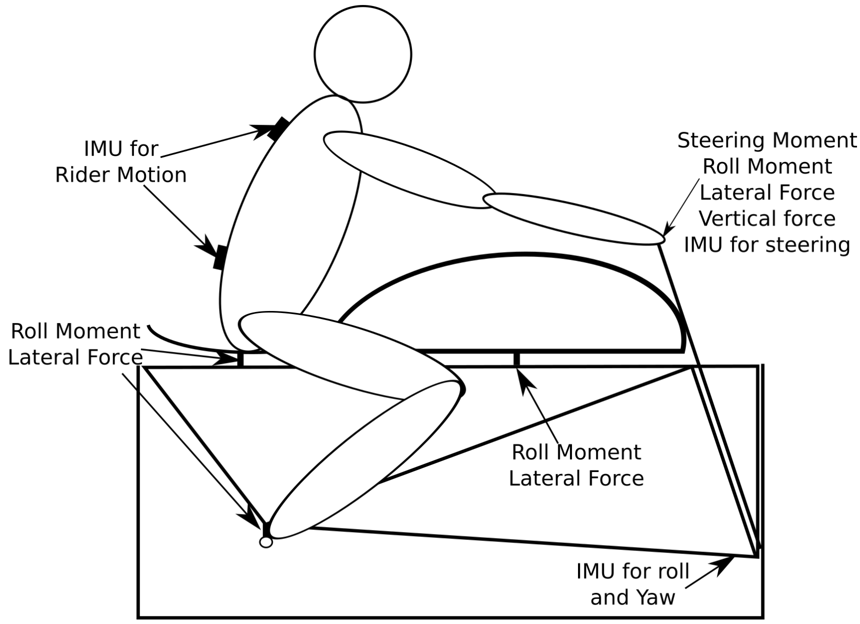


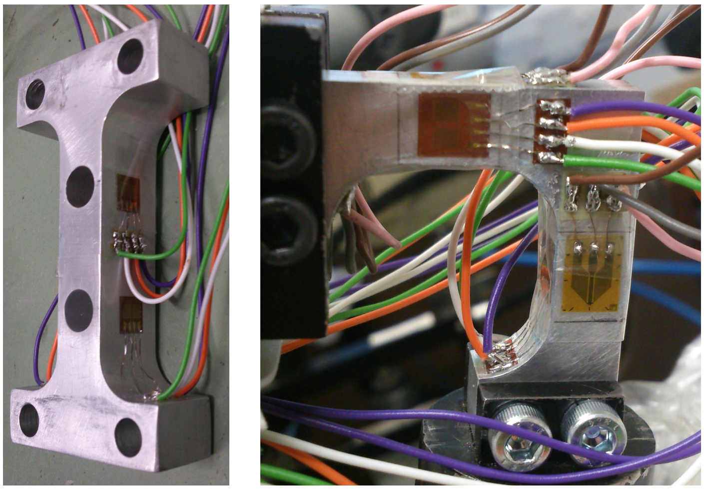
Figure 4: Measurement locations for the motorcycle shaker rig

Sensors

The main benifit of this test rig, over those used in previous investigations, is the number of measurements availiable. For rider stability models, it is common to measure only steering angle and torque [1], or rig and rider rotational acceleration [2]. Only recently have investigations been made into how the rider applies roll torque to the motorcycle, using the handlebars, footpegs and their knees on the tank. Whilst this is a good start, these investigations only provide limited information [3], or don't look at the rider's passive response [8]. This rig will measure forces and torques generated by the rider, in numerous locations, in addition to the rig's own movement, as shown in Figure 4. Rider motion can also be measured using an extension of this system. These measurements will give a clearer idea of the rider's response, and how they interact with the motorcycle.

Bespoke force sensors were designed for this rig, so that all the desired measurements could be taken, and packaged well. These sensors are used to make connections in 4 locations, (1) handlebar to steering column, (2) tank to roll frame, (3) seat to roll frame, (4) footpeg to roll frame. These bespoke sensors allow for multiple measurements to be taken on a single element, simplifying the rig's overall design. By using two measurements of bending moment on each element, the values can be compared, to calculate the moment and lateral force applied by the rider

The footpeg and steering measuring elements are shown in Figures 5(a) & 5(b). The design of the seat and tank measuring elements, is the same as the footpeg. An I design was chosen for most elements, as it allows for easy mounting, and clearance for the attached strain gauges. The holes in the centre increase strain in the measuring area, improving measurement sensitivity, without losing stiffness in the rest of the element. As the steering system requires four measurements to be taken, a Γ shape was chosen. This shape allows steering torque, lateral force, handlebar roll torque, and downwards force to be measured in a single element. Due to the limited space, a solid element with square cross section was required. Therefore, the steering element has reduced sensitivity compared to the others.



(a) Footpeg (b) Steering

Figure 5: Measuring element designs

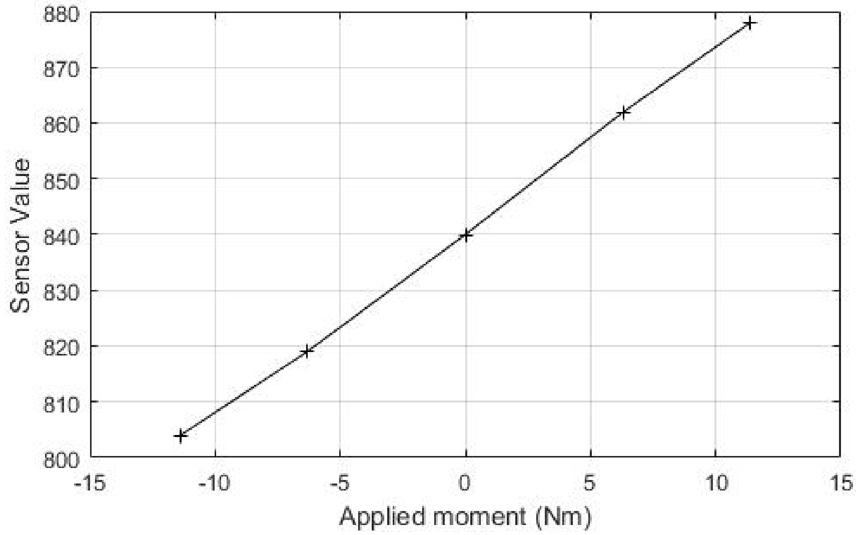


Figure 6: Calibration result for one sensor on the footpeg measuring element

To operate the strain gauges, bespoke strain gauge amplifiers are used, in conjunction with adafruit ADS1015 12-bit analogue to digital converters [13]. The strain gauge amplifiers offset and amplify the signal, to use the whole range of the Analogue to digital converters, and increase the sensitivity. The 12-bit version was chosen as this has a maximum sample rate of 3300 Hz [13], whereas the alternative 16-bit version has a maximum of 860 Hz [14]. Both of these analogue to digital converters can multiplex to measure 4 inputs each.

Figure 6 shows the data used to calibrate one sensor on the footpeg measuring element. This calibration consisted of increasing the applied moment from 0, to the maximum, then minimum, expected values, and back to 0. Five torque values were used, to assess the sensors linearity and hysteresis. This result shows the sensor has no hysteresis, and can be modelled as linear in the measurement range.

Due to the amount of rider motion data required, it was desirable to use inertial measurement units (IMUs). Most commercial solutions are expensive, and would have

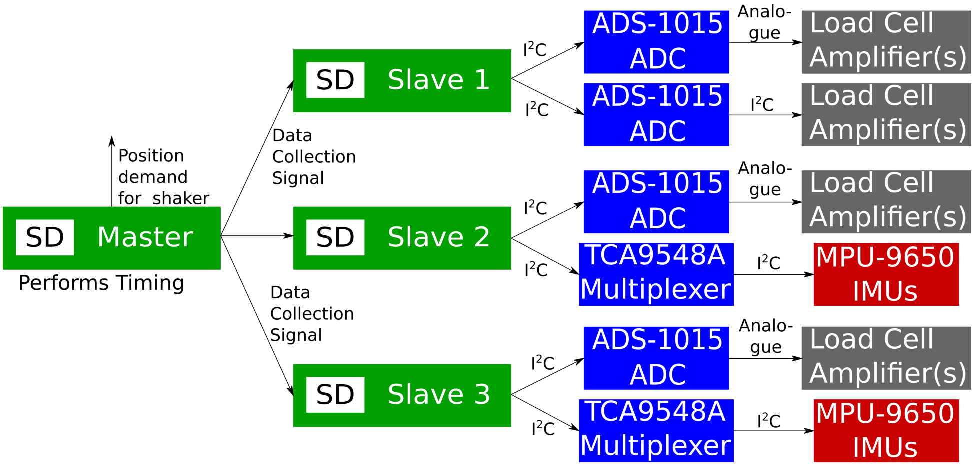


Figure 7: Graphic showing how components in the instrumentation system interact

been difficult to integrate with the rest of our hardware. To solve these issues, Low cost Microelectromechanical systems (MEMS) IMUs were chosen, and a system was built around them. The InvenSense MPU-9250, on a Spark fun breakout board [12], was chosen for this system, as it has a good response, with a smaller form factor (17 x 12 mm) than other options.

Data Collection System

As both the IMUs, and analogue to digital converters are designed to work over I^2C, commercial data collection hardware was not an easy option. As the selected sensors were designed to work with Arduino, an Arduino based micro controller was chosen to run the system. Choosing the Arduino system enabled programming to be simplified, and reduced the overall cost. After investigating the available options, the Teensy 3.5 [15] was chosen to run this system, for the following reasons:

- 3.3V operation, matching the chosen sensors
- 120 MHz clock speed, 3.75 times faster than the Arduino 101
- The built in SD card slot simplifies data storage.
- A built in real time clock, allowing for accurate time stamping

The system is connected as shown in Figure 7, Using four Teensy 3.5's. The Master Teensy provides a clock function and calculates the required position of the hydraulic shaker arm. The master does not collect data, in order to ensure that the shaker position is updated at a higher frequency than the shaker can move (to avoid jerk), and that timing pulses are sent within μs of the desired time. The data collection signal is transferred to the slaves by setting a digital pin high, which can be read and acted upon.

When the slaves read the digital pin as high, they use I^2C to request data from the load cells and IMUs. To allow multiple IMUs on the I^2C bus, the signal is passed through a Multiplexer [16], Directing the signal to one IMU at a time. The load cell output is amplified by the load cell amplifier, then the analogue to digital converter connects them to the I^2C bus, using a multiplexer to read multiple signals. Due to the number of sensors per microcontroller, and that only one sensor can be read at a time, the speed of data collection is the limiting factor for operating frequency. To avoid any errors in phase, due to these delays, each sensor result is timestamped. After all the data is collected, it is saved to the SD card of each slave, In a form that can be read by Microsoft Excel or MATLAB.

Roll Test

Here we present preliminary test data from the rig, to demonstrate some of the rig's capabilities. In this example, the rider was excited in roll, whilst holding the handlebars. A swept sine input, of constant velocity amplitude, from 0.5 Hz to 12 Hz is used for this test. The maximum amplitude used in this test is 8°.

Figure 8(a) shows that the rider's lower back experiences higher acceleration through most of the frequency range. This result suggests that the rotational acceleration of the rig is resisted by the rider's upper body inertia, and some stiffness.

It can be seen in Figure 8(b) that the roll moment applied to the seat is at a minimum between 4 & 8 Hz, before climbing again. This could indicate that the rider uses the tank, or handlebars, for more support at this frequency.

It can be seen in Figure 8(c), that the rider does apply some steering torque to the handlebar, as a result of roll motion. This torque is also frequency dependant, with an increase in magnitude after 2 Hz, which could show the rider using their arms for more support in this range at higher frequencies. This increase, along with the large phase shift, occours at the highest frquency for human control [10]. Therefore, this result may show the rider transitioning from active to passive response.

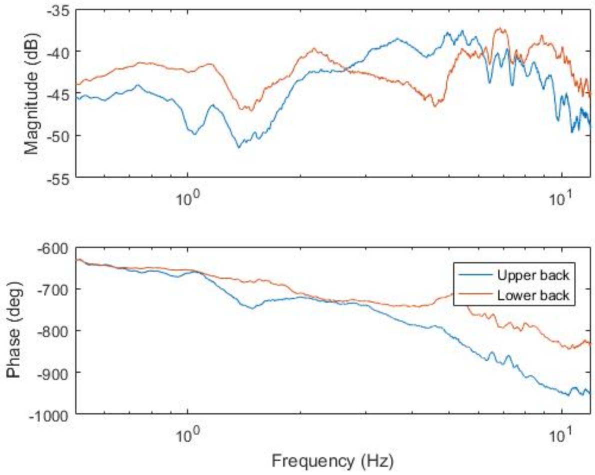
Conclusion and future work

This paper has presented the key design points of a new motorcycle shaker rig, that will be used for motorcycle rider impedance measurements. The rig can perform steering, roll and yaw motions, replicating the most important components of weave and wobble. To ensure the rig's ergonomics were correct, the control locations of nine motorcycles were measured, and replicated. The measurements showed a large variation in height between the seat and the handlebars, so an adjustable steering column was designed. This column will also allow the effect of posture to be studied for the first time. Custom force sensors were also introduced, that are designed to allow multiple force and moment measurements to be taken by each component. Preliminary results have been presented, to show some of the rig's capabilities, and some of the new transfer functions that can be examined.

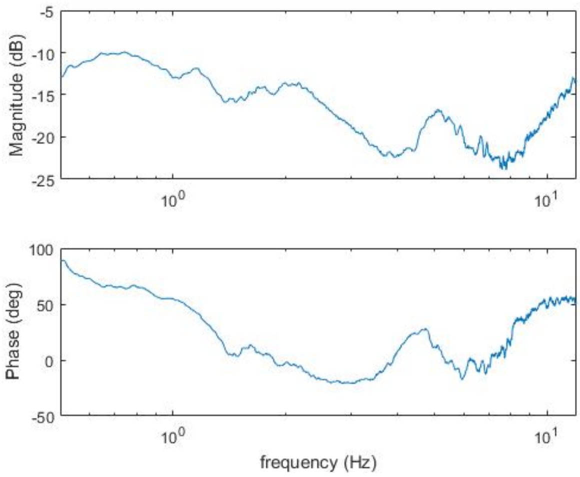
During further testing, this rig will provide more complete data on the interactions between rider and motorcycle. This data will allow more representative models of rider impedance to be created, and the causes of variation better understood. In turn, these new models can be used to improve motorcycle stability, regardless of the rider.

Acknowledgements

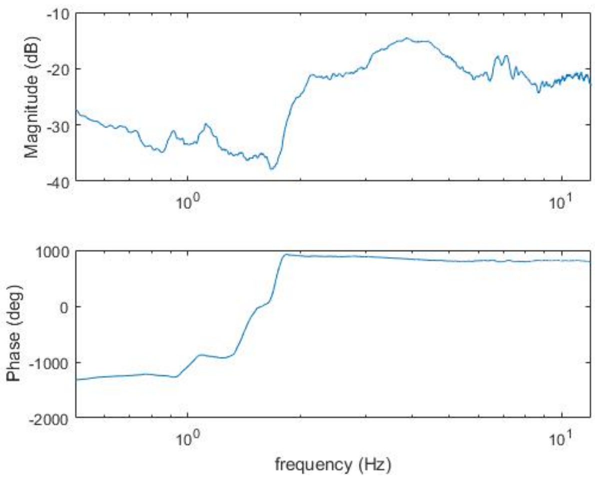
This research is funded by the ESPRC. As only preliminary data was used to illustrate this instrumentation system, it has not been made available. Data from this project will be made available, when further results are presented.



(a) FRF of rider lateral acceleration (at the back) / rig rotational velocity



(b) FRF of seat moment / rig rotational velocity



(c) FRF of steering torque / rig rotational velocity

Figure 8: Example Frequency Response Functions

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