Analysis Of Bahrain GP Circuit for Use in Motogp with Account for Gyroscopic Effect of Wheels on Speed and Lean Angle

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Abstract

Motorcycle racing is an exhilarating and demanding sport that requires riders to master a variety of skills and techniques. Among these, counter-steering and leaning the motorcycle are paramount for achieving efficient and safe cornering. Unfortunately, a significant number of major accidents in motorcycle racing occur during the cornering phase, particularly near sharp corners on racing tracks. To mitigate these risks and ensure rider safety, this research project focuses on the dynamic analysis of the gyroscopic couple effect on motorcycle wheels with the aim of determining the safe angle of heel for more efficient and secure cornering.

The gyroscopic couple effect is a phenomenon resulting from the rotation of the wheels on a motorcycle. It generates a stabilizing force that significantly impacts the motorcycle's stability and control when in motion. Understanding how this effect influences motorcycle behavior is pivotal in optimizing cornering performance while ensuring rider safety.

The safe angle of heel, often referred to as the lean angle, is a critical parameter in motorcycle racing. Achieving the optimal lean angle is a delicate balance between maximizing tire grip and maintaining control. Inappropriate lean angles can lead to traction loss and catastrophic accidents. Therefore, this research aims to conduct a comprehensive dynamic analysis of the gyroscopic couple effect to calculate the safe angle of heel accurately.

Introduction:

Racing is a universally celebrated motorsport enjoyed by enthusiasts worldwide. MotoGP, organized by the Fédération Internationale de Motocyclisme (FIM), is among the most renowned racing competitions. Participation in racing necessitates riders of exceptional skill and training, adept at techniques such as counter-steering and sliding. However, a significant portion of racing accidents occurs due to the high speeds of motorcycles and the presence of sharp, 150-degree bends. Recognizing the influence of the gyroscopic couple effect on motorcycle wheels during cornering, this research endeavors to explore the potential of employing a reactive gyroscopic couple to enhance rider safety. Additionally, this study aims to identify the ideal tire material and hardness, contributing further to safety improvements in racing.

The gyroscopic couple effect is a fundamental factor affecting motorcycle stability and control. It arises from wheel rotation and plays a crucial role in preserving balance and maneuverability during cornering. This research delves into the application of a reactive gyroscopic couple to bolster rider safety when tackling the challenges presented by sharp bends on the racing track.

Determining the safe leaning angle is of paramount importance in ensuring rider safety in high-speed racing. This research seeks to establish the optimal angle of lean that, when achieved, effectively harnesses the reactive gyroscopic couple, thereby reducing the risk of accidents during cornering.

In addition to gyroscopic considerations, the selection of tire material and hardness is pivotal for performance and safety in racing. This research aims to identify tire materials and hardness levels that strike the right balance between grip, longevity, and safety in racing conditions.

Counter-steering and its needs

Initiating a turn on the racing track is a fundamental skill in motorcycle racing, and achieving this requires disrupting the linear moment of inertia of the motorcycle. This disruption is accomplished through the utilization of the stabilizing force generated by the gyroscopic effect on the two wheels. This concept is a ubiquitous and integral aspect of racing, employed not only for initiating turns but also for executing overtaking maneuvers by exploiting the slipstream.

Angle of heel

MotoGP riders demonstrate remarkable skills when it comes to using counter-steering techniques. This enables them to lean into corners while maintaining speeds of up to 130 kilometers per hour, achieving a maximum lean angle of 60 degrees.

Angle of heel can be calculated by following formula -

Formula

$$\theta = arctan\left(\frac{v^2}{rg}\right)$$

Where,

v = linear speed

r = radius of turn

g = acceleration due to gravity

Methodology

For the purposes of this research, the selected track is the 'Bahrain International Circuit,' situated in Sakhir, Bahrain. This circuit has been meticulously designed in accordance with the 'Grand Prix' standards and boasts a total of 15 turns, covering a track length of 5.412 kilometers. Notably, this specific track has never been used for testing a MotoGP bike before, which posed a challenge in obtaining standardized data for the motorcycle's parameters.

For calculation of all the table data, numerical method is used. First all standard required parameters were inserted in Excel. Then by governing equations further parameters such as velocities and resultant force were calculated.

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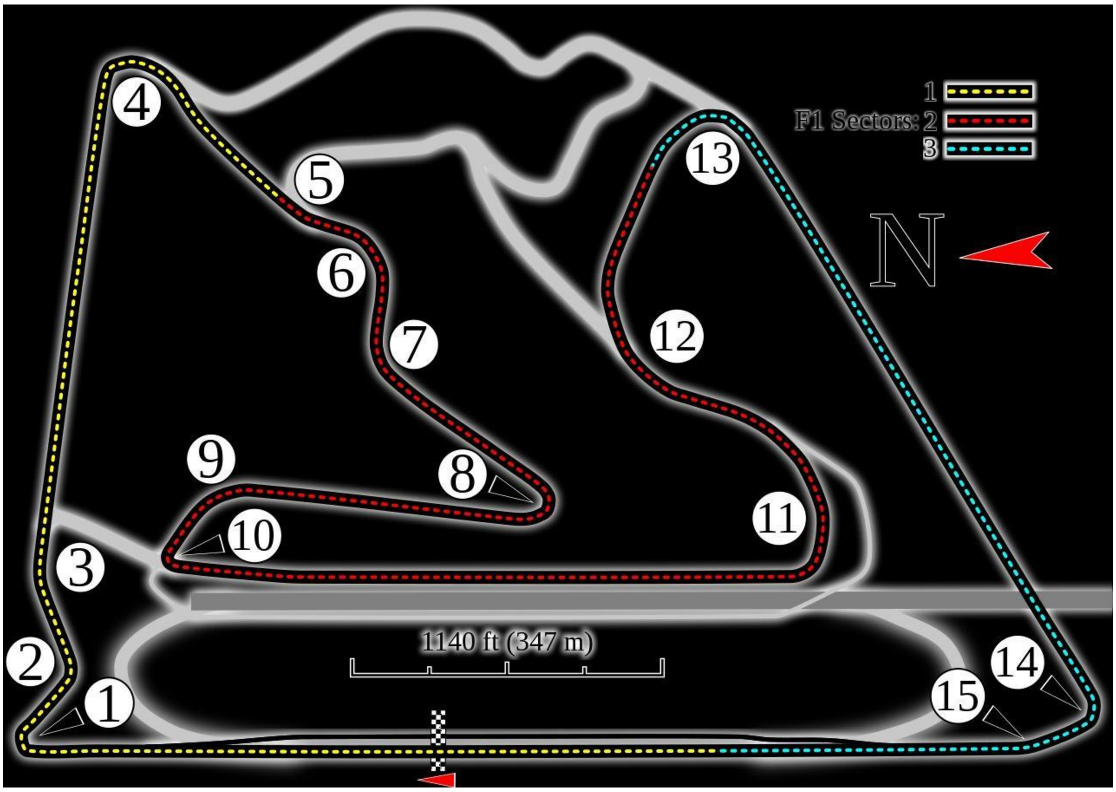

Diagram 1

Turn no.	Angle	Direction	Radius
1	135	R	9
2	60	L	18
3	25	R	96
4	135	R	13
5	15	L	120
6	60	R	57
7	60	L	67
8	150	R	15
9	45	L	74
10	135	L	7
11	135	L	34
12	90	R	108
13	120	R	29
14	90	R	18
15	15	R	99

Calculations of angle of heel and associated velocities

When a rider leans the motorcycle at a maximum angle of 60 degrees with respect to the vertical y-axis while taking a turn at higher speeds, the gyroscopic effect induced by this leaning action can pose potential risks to the rider, potentially leading to loss of control.

To address this challenge, a different approach is considered for maintaining safety during cornering. Instead of focusing solely on maintaining the angle of lean, the research aims to calculate the velocity at which the motorcycle should be operated for safe maneuvering on the track. This approach takes into account various factors, including the curve's geometry, the motorcycle's stability, and the rider's control, to determine the optimal speed for negotiating turns safely.

Formula

$$\theta = arctan\left(\frac{v^2}{rg}\right)$$

We have taken the angle of heel as 10° to 60° and calculated velocities which are as follows.

Turn no.	**Velocity for Theta = 10° (kmph)**	**Velocity for Theta = 60° (kmph)**
1	14.20422832	44.51830011
2	20.08781234	62.95838379
3	46.39081545	145.3961593
4	17.07135785	53.50433792
5	51.86650843	162.557848
6	35.74652404	112.0352651
7	38.75553989	121.4659971
8	18.33757991	57.47287831
9	40.7297974	127.6536326
10	12.5269519	39.26145029
11	27.60805735	86.52802213
12	49.20489028	154.215915
13	25.49737016	79.91279434
14	20.08781234	62.95838379
15	47.11009579	147.6504978

Defining material and hardness of tyres

In order to define the material hardness and grade of a bike tire effectively, it is imperative to understand the various forces exerted upon the tire. To achieve this understanding, we have referenced the following Free Body Diagram (FBD). This FBD serves as a foundational framework for analyzing and comprehending the forces that impact the tire's performance, allowing us to make informed decisions regarding tire material properties and grade selection.

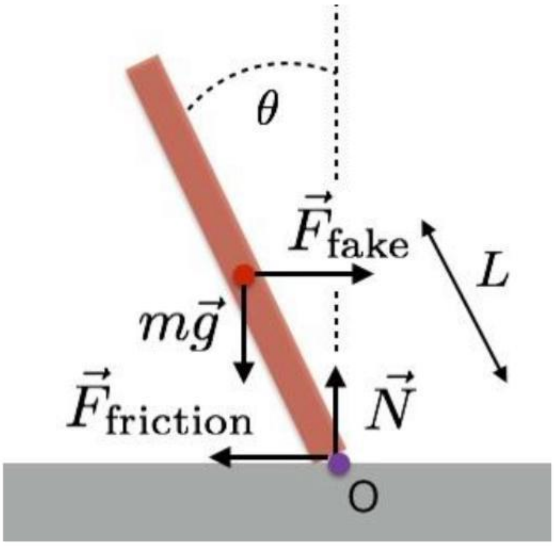

Diagram 2

From above FBD, Resultant force can be written as,

$R^2 = ((mg)^2 + (mv^2 /r - \mu mg)^2)$

The equation's analysis reveals that the resultant force acting on the wheel is directly proportional to velocity and inversely proportional to the radius (1/r). Leveraging this relationship, we have computed essential values from Table 2, including the maximum velocity attainable, associated turn radius, and the minimum allowable radius with its corresponding velocity.

Our calculations according to have determined that the maximum resultant force exerted on the tires is 2795 Newtons. As a result, the appropriate tire hardness number is 65. Additionally, it has been determined that the motorcycle can reach velocities of up to 300 kilometers per hour when traveling in a straight line, making it suitable for the use of Z-grade tires. In the context of braking forces, which approach approximately 1.5 times the force of gravity (1.5G), a grade of 71 could be considered. However, for safety considerations, a grade of 72 is commonly employed. These calculations and grade selections are made to ensure optimal performance and safety in various riding conditions.

Now in MotoGP even we have assymetrical tyre compound and for this circuit considering more no. of right turns we will use Hard or medium right side compound with soft compound on left side.

	Load (kg)
62	265
63	272
64	280
65	290
66	300
67	307
68	315
69	325
70	335
71	345
72	355
73	365
74	375
75	387
76	400
77	412
78	425
79	437
80	450
81	462
82	475
83	487
84	500
85	515
86	530
87	545
88	560
89	580
90	600
91	615
92	630
93	650
94	670
95	690
96	710
97	730
98	750
99	775
100	800
101	825
102	850
103	875
104	900
105	925
106	950
107	975
108	1000
109	1030
110	1060
111	1090
112	1120
113	1150
114	1180
115	1215
116	1250
117	1285
118	1320
119	1360
120	1400
121	1450
122	1500
123	1550
124	1600
125	1650
126	1700

	KM/H	MPH
F	80	50
G	90	56
J	100	62
K	110	68
L	120	75
M	130	81
N	140	87
P	150	93
Q	160	100
R	170	106
S	180	112
T	190	118
U	200	124
H	210	130
V	240	149
W	270	168
Y	300	186
(Y)	300+	186+

MotoGP bike specifications

Engine-999cc (V4 or Inline-4)
Horsepower - 260+ hp
Brake Disc - Carbon Ceramic(Dry Setup)
Steel Ventilated (Wet Setup)
Weight of Bike - 150 kgs
Weight of rider - 75 kgs(with full kit)

Fuel Consumption of MotoGP bike

In MotoGP bikes we get a approximate of 22 Litres of fuel and average race distance is 110 kms,now according to the length of one lap of circuit we decide number of laps.

For example, Bahrain GP one lap is around 5.4 kms we can have around 22 laps as this circuit demands less momentum changes and favours long sweeping corners.

Conclusion

This research carries substantial implications for the prediction of safe speeds and lean angles during both training and racing scenarios. By leveraging the insights gained from this study, riders can significantly enhance their safety factors while competing. Furthermore, the dynamic analysis conducted in this research provides a predictive framework for assessing loads and their distribution in both tires, thereby aiding in the selection of appropriate tires for racing.This track gives us 22 laps as race distance considering this circuit demands less momentum changes and favors long sweeping corners.

Additionally, this research introduces an innovative approach to defining tire hardness, which can have profound implications for tire design and selection.

By utilizing the findings from this analysis, riders can confidently maintain their motorcycles at specified speeds for various turns, ensuring that the angle of lean remains within the safe range of 10° to 60°, thereby facilitating secure maneuvering on the Bahrain GP Track. In summary, this research has successfully calculated the essential parameters necessary for safe riding on this track, contributing significantly to rider safety and the overall enhancement of the racing experience.

We have also analyzed track that has never witnessed MotoGP Races and we have also specified the number of laps that should be done for the race by virtue of considering fuel consumption.