Lateral Force Modelling Using Magic Formula Tire Model

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Abstract The aim of this paper is to explain one of the methods that can be used to fit the Pacejka Magic Formula Model for the lateral behaviour of the tire. The content gives the readers an idea in order to utilize data and model tire behaviour. The tool used for the purpose of explanation is MATLAB.

Keywords Tire modelling · Lateral force · Magic formula · Pacejka model

1 Introduction: The Tire Tests [1]

The procedure of the test involves starting with the measurement of spring rate at 0 and 25 mph. Following which, the 'cold-to-hot' test is carried out by making 12 sweeps from $-12°$ Slip Angle (SA) to $+12°$ SA at $8°$/s. After this procedure, a warm-up run is done at 250 lbs load and 12 psi pressure for about 1 min. Once these tests are completed, the tires are tested to gather the data for pure cornering conditions. This is done by sweeping the tire from −12-degree SA to +12-degree SA at five different loads, five inclination angles and four pressures. The test values of these parameters are provided in Table 1.

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Table 1 The tire test data parameters

Loads (in lbs)	Inclination angles (in degrees)	Pressure (in psi)
50	0	8
100	1	10
150	2	12
250	3	14
350	4	–

2 Data Analysis and Interpretation

In order to understand the test procedure, it is easier to look at the graphs. As shown (Fig. 1) is the diagram of SA with respect to Elapsed Time (ET) for Hoosier R25B tires. From the graph, it is clearly evident that there are five differentiable parts or sweeps. As stated in the procedure, the first two sweeps are cold-to-hot and warm-up (see Fig. 2). After these, the remaining three sweeps are pertaining to 10, 12 and 14 psi pressures with all the load and inclination angle values.

The significance of the first two sweeps is to understand the generation of the temperature in the tires. By understanding the temperature range corresponding to the lateral force values, it will be easier to generate the performance when the tires are initially fitted on the vehicle (i.e. when they are cold and not at the required temperature) by getting the tires to the required temperature.

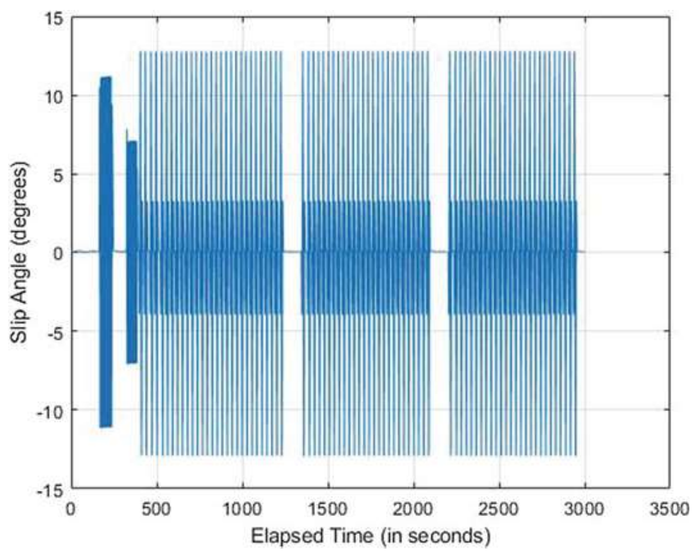

Fig. 1 Elapsed time versus slip angle showing five differentiable sweeps

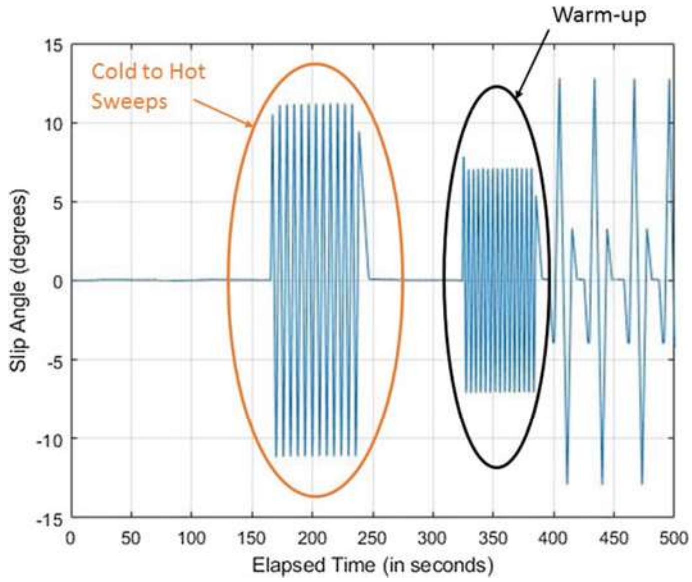

Fig. 2 Cold-to-hot and warm-up sweeps

3 Plotting Lateral Force Versus Slip Angle

Further examining the data, we can see (Fig. 3.) that the first parameter of differentiation is the tire pressure [1]. The order of the test is 82.73 kPa (12 psi), 68.95 kPa (10 psi), 96.53 kPa (14 psi). Now, we will first focus on the 12 psi data. This data is also significant because the warm-up procedure is also carried out on the same pressure; hence, it is easier to compare the effect of temperature at later stages.

Again, we can see that the sweeps can again be differentiated based on the inclination angle and normal loads. As seen in (Fig. 4.), the order of the inclination angles is 0 deg, 2 deg, 4 deg followed by 1 deg and 3 deg.

In order to simplify the understanding of the curve fitting process, we will be using the data at the 0-degree inclination angle so as to eliminate the effect of the inclination angle on the curve.

Now, the process of curve fitting is divided into the following three major parts:

i. Plotting of RAW data
ii. Creating groups based on Slip Angle
iii. Using the groups to fit the Magic Formula and find the coefficients.

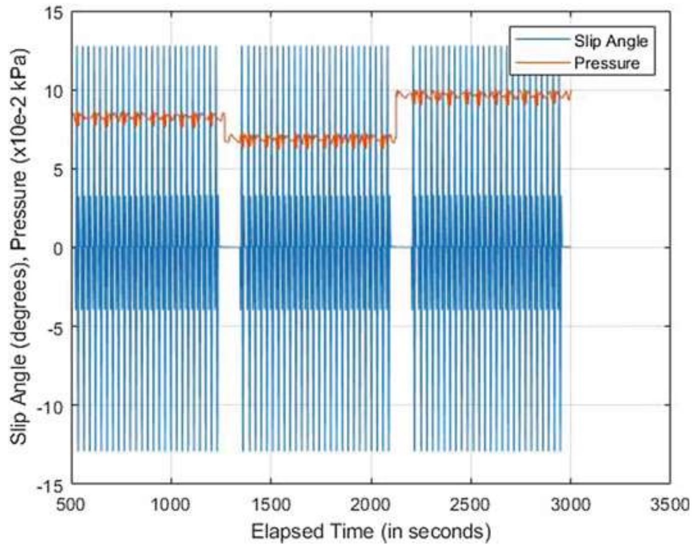

Fig. 3 The distinction of the sweeps based on tire pressure

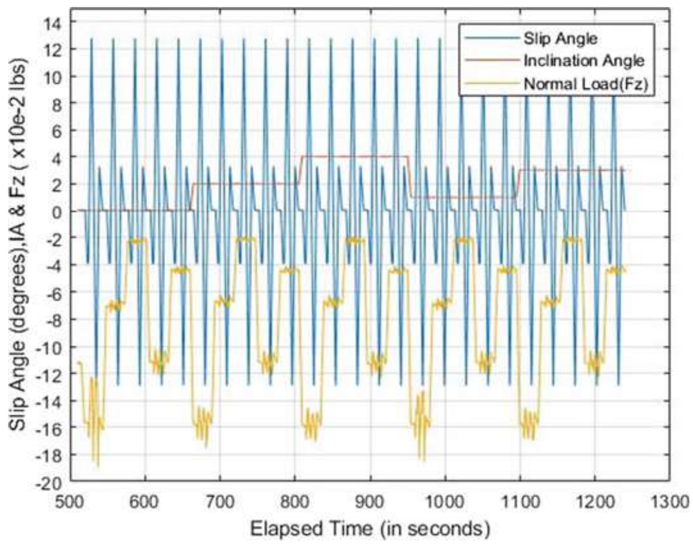

Fig. 4 SA, IA and F_z for 12 psi

3.1 Plotting the RAW Data

RAW data is nothing but the unfiltered data that is recorded by the sensors during the test. Plotting these values will help us visualize the behaviour of the tire in its organic

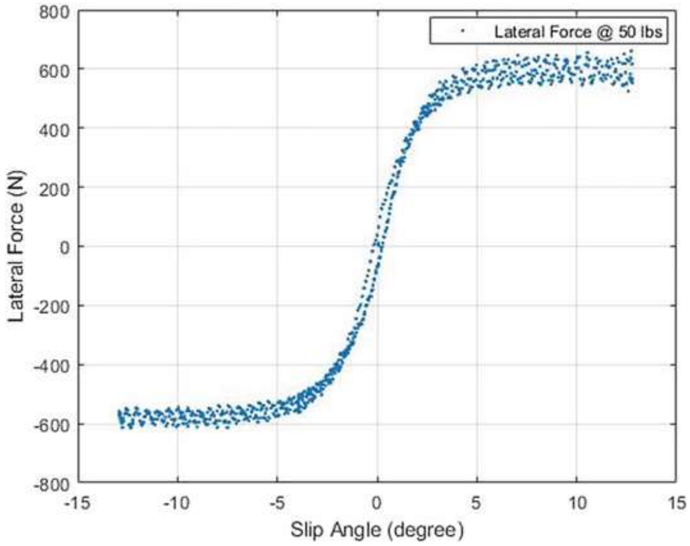

Fig. 5 RAW data plot

state (i.e. without approximations of curve fitting). We can observe that the amount of data points is vast. If we are to use this data to produce a curve, there is ought to be a large amount of deviation because there is a lot of variation for each of the slip angle values. Hence, it is important to filter this data based on certain tolerances. In order to filter the data, the primary parameter will be the slip angles. Since, the Magic Formula tire model is dependent directly on slip angle, forming groups-based slip angle values and their corresponding lateral force values is convenient (Fig. 5).

3.2 *Creating Groups Based on Slip Angle*

As explained earlier, the slip angle values vary from -12 to $+12°$. Owing to the fact that the control of the machine[1] at low loads is weak, we will need to have a tolerance of $\pm 0.5°$. Hence, for the purpose of filtering the range of slip angle will vary from -12.5 to $+12.5°$. Now, using MATLAB we will create matrices for SA and FY for values of SA starting from $-12.5°$ with an increment of $0.2°$. After finding the corresponding values of lateral force for the slip angles, the mean values of the forces will be calculated and plotted against these slip angle values (Fig. 6).

Hence, now we can see a clear path for the Magic Formula curve to pass through. The key to filtering the data is to identify the key parameter and define the tolerance such that there is the elimination of unwanted data while not missing out on key data values.

[1]Calspan Tire Research Facility (TIRF).

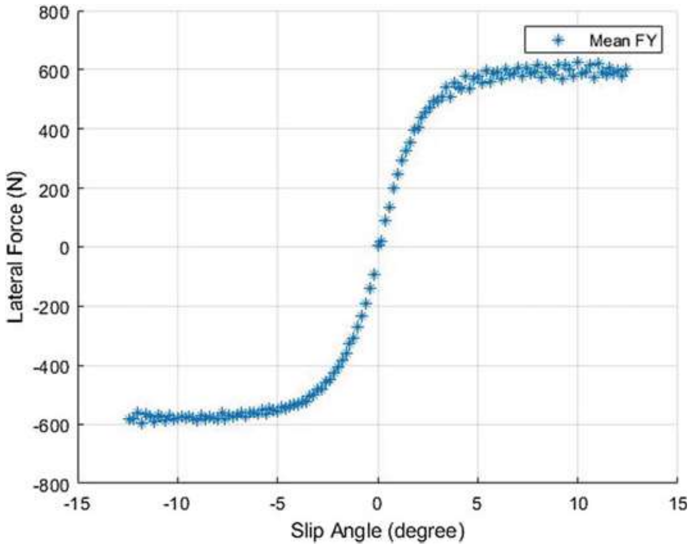

Fig. 6 Filtered data

3.3 Using the Filtered Data to Fit the Magic Formula and Find the Coefficients

The next step is to find the values of the coefficients and fit the Magic Formula [2–4]. In order to find the coefficients, we will need to understand the meaning of each of them.

i. **B—Slope Factor**: The slope of the curve at near 0 slip angle. It is also important to find the value of the cornering stiffness of the tire.
ii. **C—Shape Factor**: The shape of the curve at the peak during the transition phase is controlled by this coefficient.
iii. **D—Peak Factor**: The maximum value of the lateral force.
iv. **E—Curvature Factor**: The curve drops off after reaching the peak. This drop is controlled by increasing the influence of 'sine' function and the coefficient responsible for that is *E*.
v. **SHY & SVY—Horizontal and Vertical Shifts**: The properties of the tire that are described as ply steer and conicity give rise to these coefficients.

Once we have understood the meaning of each of the coefficients, using the equations provided for the Magic Formula we can find the values. Hence, using the filtered data, we can assign D as the maximum value of FY. Next, we need to define X_m and $Y_a$which are necessary to find C and E. X_m is nothing but the value of slip angle for the corresponding value of D. Y_a is defined as the minimum value of FY after the peak has been reached [4]. Once the variables have been defined, all that is needed is to plot the RAW data and Magic Formula curve and compare.

As we can see (Fig. 7), the curve is not a perfect fit. The reason for this deviation lies in the value of B. The coefficient value generated by the code is not accurate. By defining the value of this variable manually, we can get rid of the error (see Fig. 8).

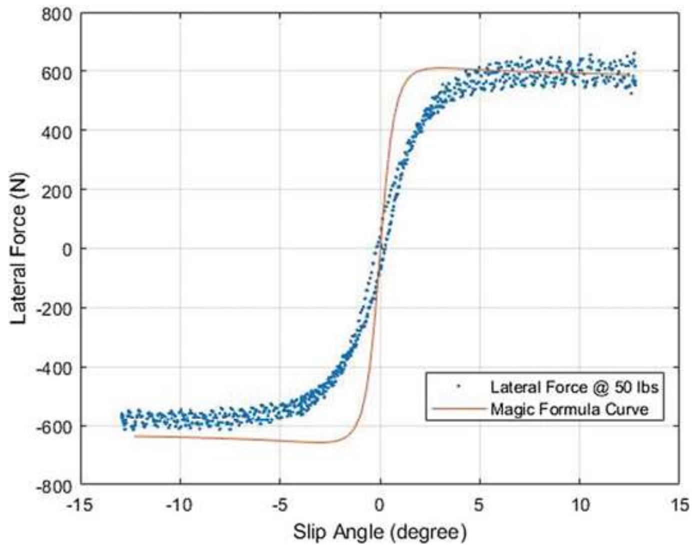

Fig. 7 Magic formula curve

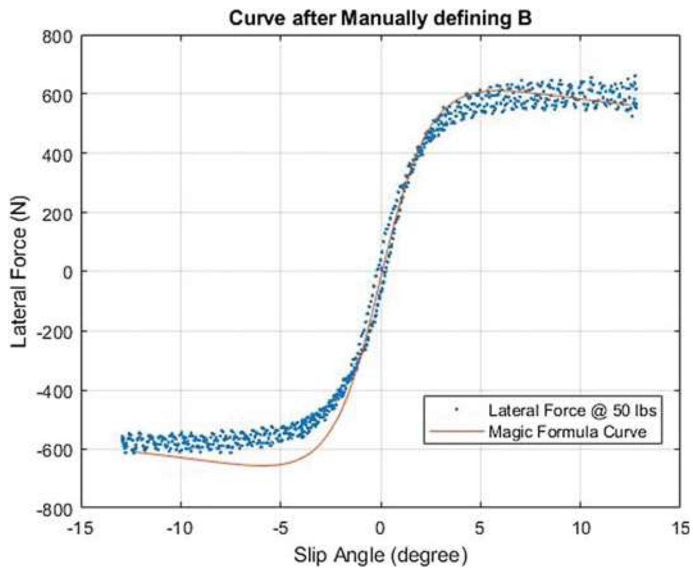

Fig. 8 Eliminating the error in B

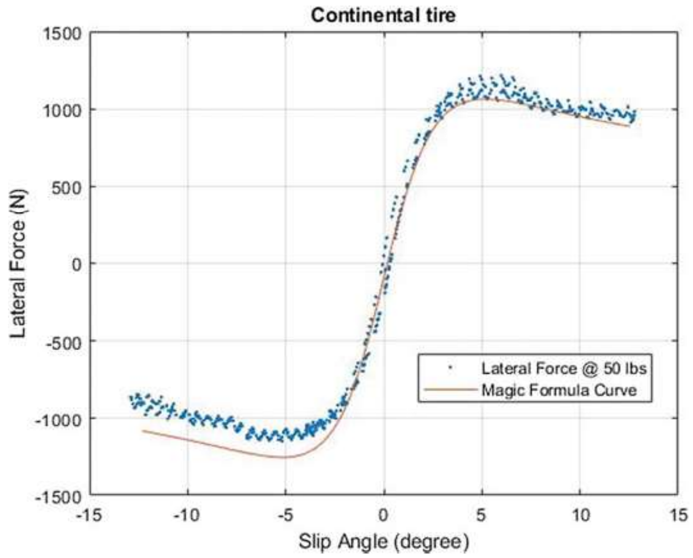

Fig. 9 Continental tire fit

In order to examine the validity of the code for a different tire, given below is the graph for the radial-ply continental tire (Fig. 9).

4 Conclusion

The study was carried to look into the lateral force modelling aspect of Magic Formula tyre model in vehicle dynamics. The parameters to judge the effectiveness of the approach will depend upon the error. The error is the deviation of the Magic Formula curve passing through the RAW data. Using the above-described approach, the Magic Formula curve with considerable error is achieved. Since the tire model will affect the complete performance of the vehicle, it is necessary to reduce the error as far as possible. In order to reduce the error, refined regression techniques will be required. Yet, using the current estimations, the effect of temperature on the generation of lateral force can be analyzed by comparing the FY versus SA curves during warm-up procedure and the sweeps after that. Furthermore, the outcome of the approach provides the base to start the development of the mathematical model of the vehicle to analyze and improve the performance.

5 Future Work

i. Utilizing the list of equations for the lateral dynamics, generating a more accurate curve [4].
ii. Understanding the effects of temperature.
iii. Generating a relation between tire wear and the decrease in the lateral force.
iv. The change in behaviour after re-treading the same tire.

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