Tyre data fitting

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Lateral Force Fitting

The analysis started from the "Cornering" dataset *'HoosierB1464run23'*, useful to devise the pure slip lateral force coefficients. In the order, the pure slip lateral force for zero camber and nominal load, zero camber and variable normal load, and nominal load with variable camber curves were fitted. Some of the criteria used are $pCy1 \geq 1$, $pEy1 \leq 1$ for F_{y0}. ISO reference frame was used as convention for the Magic Formula.

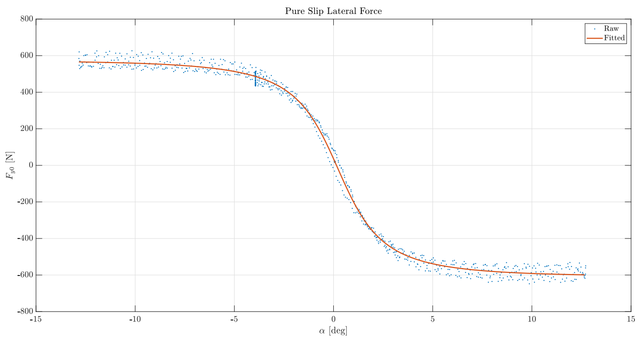

Figure 1: Pure Slip Lateral Force with Normal load and $\gamma = 0$

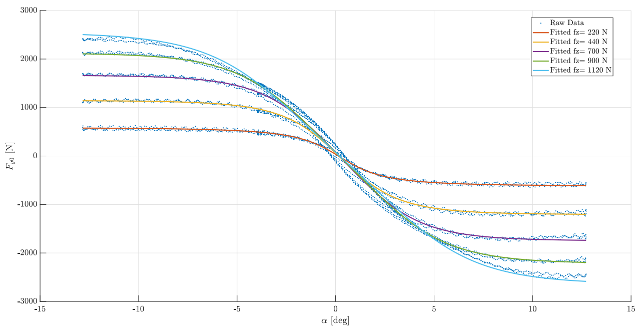

Figure 2: Pure Slip Lateral Force with variable Fz

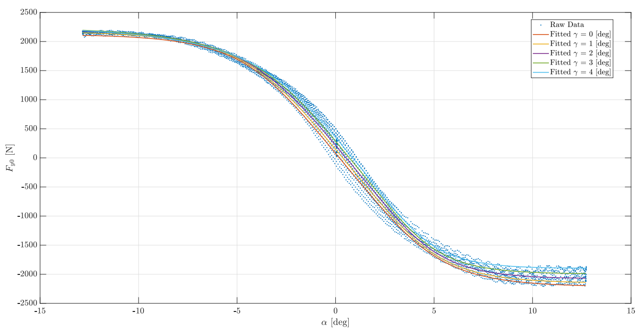

Figure 3: Pure Slip Lateral Force with variable γ

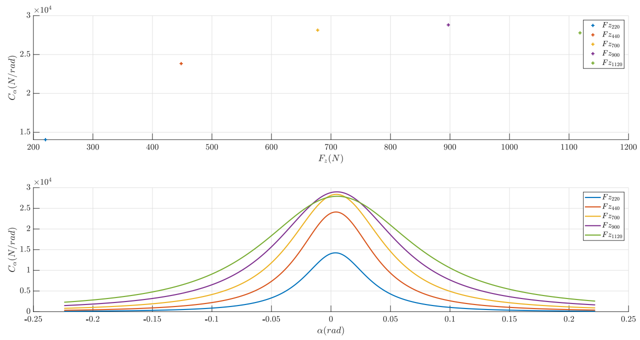

Figure 4: Cornering Stiffness C_α

Self Aligning Moment Fitting

As shown in table: 2 the error of these fitting is greater than the rest of the coefficients due to noisy data and thermal hysteresis of the tyre. To reduce the error the data was pre-processed removing messy data and outliers, this improved the result even though the errors are still relevant.

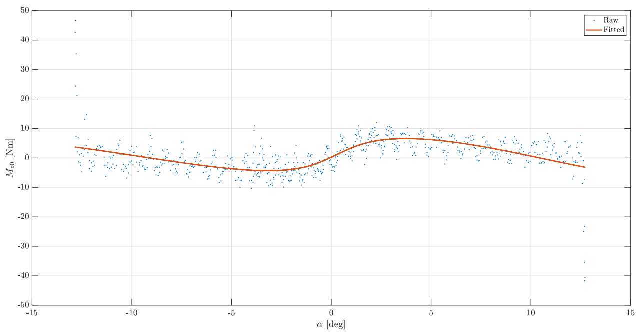

Figure 5: Pure Slip Self Aligning Moment in Nominal conditions

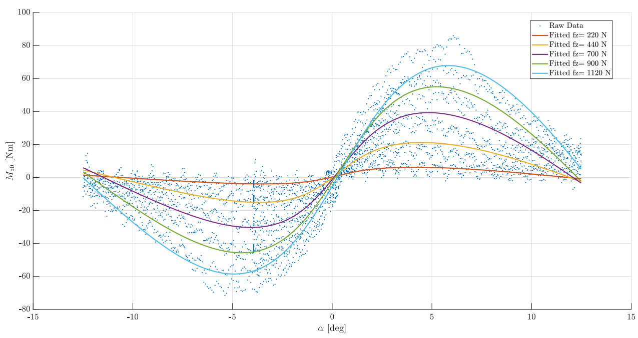

Figure 6: Pure Slip Self Aligning Moment with variable Load

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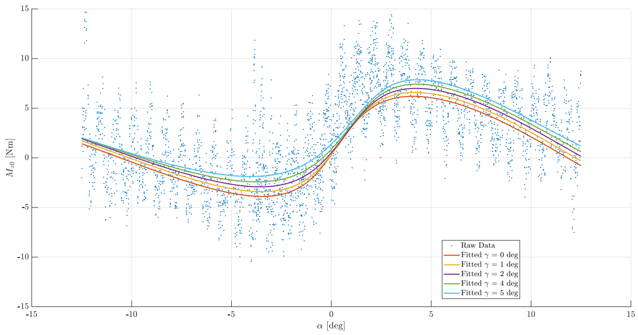

Figure 7: Pure Slip Self Aligning Moment with variable γ

Longitudinal Force Fitting

Subsequently, the dataset were switched, passing to the "Braking/Traction" set *'HoosierB1464run30'*, to fit longitudinal and combined parameters.

First, the group of parameters relative to the nominal conditions were fitted. Next, the parameters that were dependent on different vertical loads were fitted. Following this, the group of parameters that were dependent on the camber angle were fitted. Finally, the combined behavior for Fx and Fy were plotted.

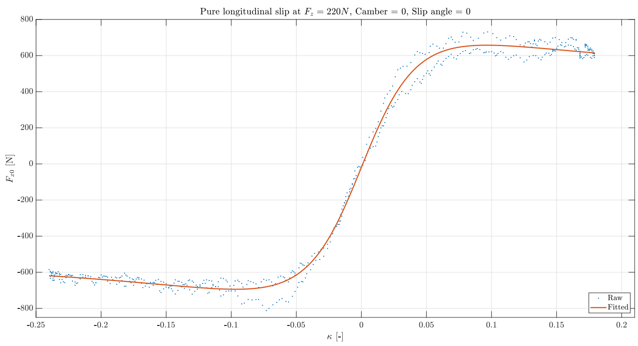

Figure 8: Pure Slip Longitudinal Force with Normal load and $\gamma = 0$

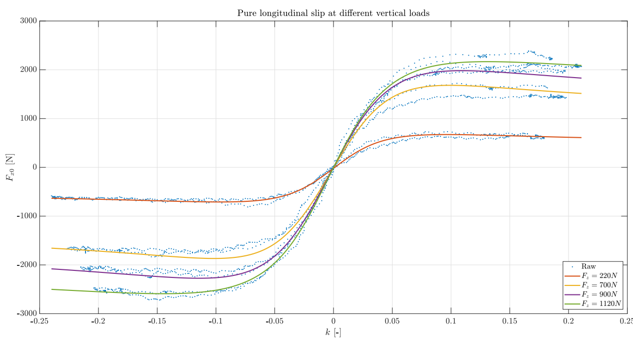

Figure 9: Pure Slip Longitudinal Force with variable Fz

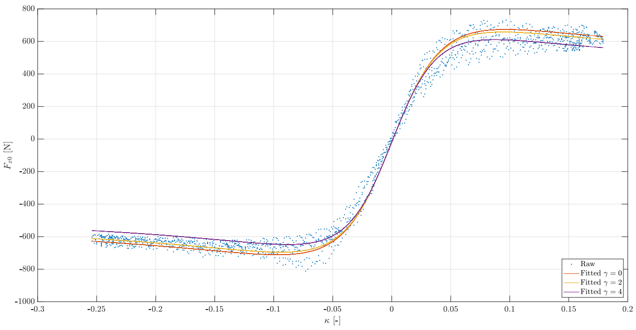

Figure 10: Pure Slip Longitudinal Force with variable γ

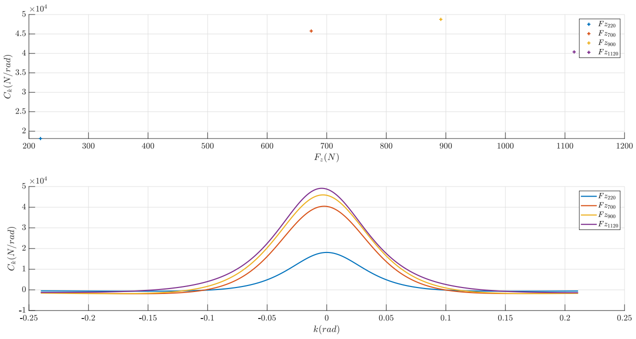

Figure 11: Cornering stiffness C_k

Combined Slip Fitting

The combined slip longitudinal force was found by fitting $Fx(\kappa)$ for the three constant levels of side slip α. The nature of the data that made easy to analyse the longitudinal force combined behaviour, i.e. a sweep of longitudinal slip k while the side slip α was kept constant, forced the fitting of the combined slip lateral force as function of the longitudinal slip $F(k)$, hence differently from the expected procedure. Nonetheless the fit was of discrete quality.

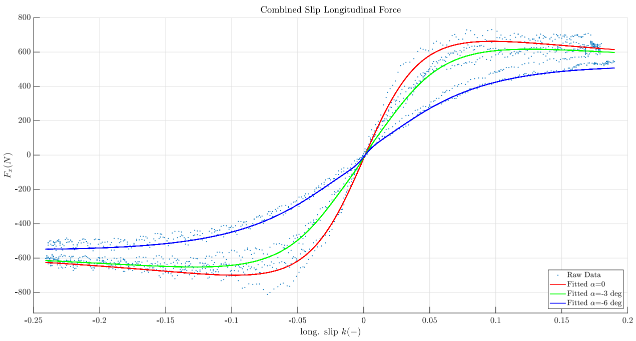

Figure 12: Combined Slip Longitudinal Force with Nominal Conditions

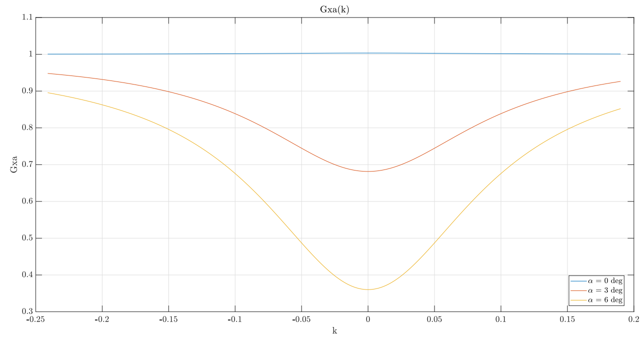

Figure 13: Combined Slip Longitudinal Force Weights

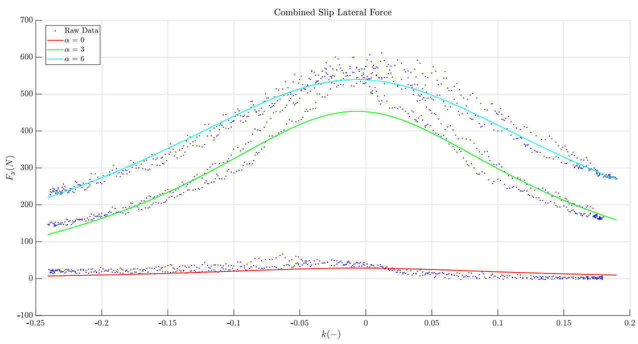

Figure 14: Combined Slip Lateral Force with Nominal Conditions

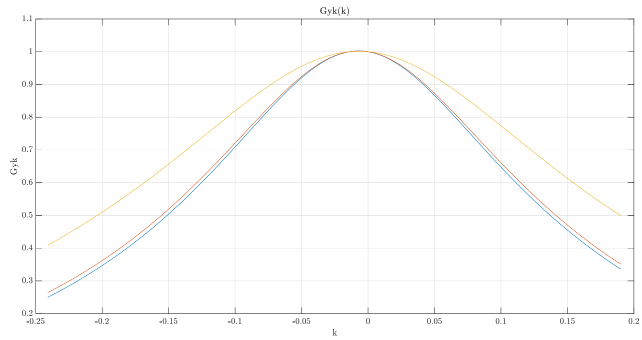

Figure 15: Combined Slip Lateral Force Weights

In addition, having obtained the coefficients from the data, the lateral force in combined conditions was devised using as input a sweep in side slip and various steps of slip ratio, as shown in fig.: 16.

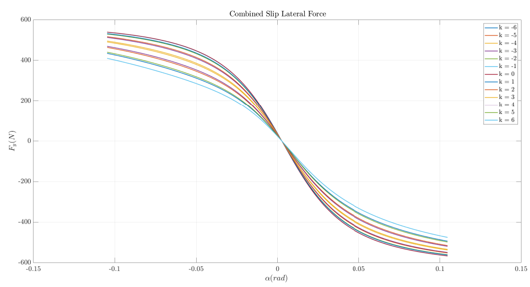

Figure 16: Combined Slip Lateral Force in α

Fitting Problems

In the analysis various fitting problems were encountered, most of which then solved. Problems due to the lack of experience in the matter, that turned out to be the most crucial factor in the choice of a feasible initial point (and bounds) for the optimisation algorithm in order to converge towards a global minima, rather than on one of the plentiful local minima.

To solve this problem various approaches were used. Firstly, the selection of feasible parameters from literature as initial conditions of the optimisation, secondly, the use of different functions to fit the parameters, both by minimising the residuals function and by feeding directly the magic formula to the function. Some examples of other approaches tried are: `fminunc`, `GlobalSearch`, `MultiStart`, `lsqcurvefit`, `lsqnonlin`. In the end the best approach seemed to be the iterative search of ideal minima by varying the lower and upper bounds and looking at the trend the magic formula took, trying to match data. This method is obviously very slow and counters the fundamental convenience of using an optimisation algorithm.

Conclusion

In conclusion the parameters devised are resumed in the following tables, with the corresponding values of R^2 and $RMSE$ for each fitting.

FX0		FY0	
Coeffs.	***Values***	***Coeffs.***	***Values***
pCx1	1,546327262	pCy1	1,125413002
pDx1	3,147574301	pDy1	2,719037683
pDx2	-0,249527382	pDy2	-0,00369247
pDx3	18,45695812	pDy3	-12,77915138
pEx1	0,036717117	pEy1	0,44381473
pEx2	-0,358057393	pEy2	0,07408082
pEx3	0,103762425	pEy3	-0,015438403
pEx4	0,115754231	pEy4	18,28693328
pHx1	-3,33148E-05	pHy1	-0,003802201
pHx2	0,001050904	pHy2	-0,000369023
pKx1	82,50472083	pHy3	-0,298877609
pKx2	-0,001987942	pKy1	-132,0477919
pKx3	0,154120909	pKy2	3,824584973
pVx1	-0,085618137	pKy3	1,948841815
pVx2	-0,025613553	pVy1	-0,079215501
		pVy2	0,007550046
		pVy3	-0,347164448
		pVy4	-1,068814515

Table 1: Pure Slip Coefficients

MZ0		Combined	
Coeffs.	***Values***	***Coeffs.***	***Values***
qBz1	0,934378728	rBx1	5,487413021
qBz10	-14,96994608	rBx2	1,722796132
qBz2	-0,088686467	rBy1	8,389369795
qBz3	0,006333251	rBy2	12,07714462
qBz4	-2,081171671	rBy3	-0,021217525
qBz5	3,832285857	rCx1	1,01055752
qBz9	-0,429345495	rCy1	1,214428021
qCz1	17,66130502	rHx1	-10,94065665
qDz1	0,050951797	rHy1	0,007012215
qDz2	-0,003539464	rVy1	0,01
qDz3	-0,102720759	rVy2	0
qDz4	1,697368877	rVy3	0
qDz6	14,02717545	rVy4	50
qDz7	-3,919436005	rVy5	1
qDz8	818,9387978	rVy6	20
qDz9	9,269387324		
qEz1	-1,159500323		
qEz2	0,556772865		
qEz3	-0,044811202		
qEz4	0,846107656		
qEz5	2,639532094		
qHz1	-0,99959582		
qHz2	-0,066458757		
qHz3	0,998402251		
qHz4	0,115366218		

Table 2: Combined Slip and Self Aligning Moment Coefficients

	R2	**RMSE**
F_{y0}	0.9963	28.24815
$F_{y0}(dF_z)$	0.9972	66.6612
$F_{y0}(\gamma)$	0.9978	72.3553
M_{z0}	-530434.7481	3460.9169
$M_{z0}(dF_z)$	-57683703.4677	210883.5080
$M_{z0}(\gamma)$	-9.7223	16.9713
F_{x0}	-2.5719	1135.6400
$F_{x0}(dF_z)$	0.9971	85.9577
$F_{x0}(\gamma)$	0.9938	45.8400
$F_x(k)$	0.9931	44.4064
$F_y(k)$	0.6143	190.8082

Table 3: R^2 and $RMSE$ of fitting