Optimal Design of Motorcycle Rear Suspension Systems Using Genetic Algorithms

Chapter · January 2013

DOI: 10.1007/978-94-007-4902-3_19

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Optimal design of motorcycle rear suspension systems using genetic algorithms

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Abstract - Acceleration, braking and turning capabilities are widely influenced by the parameters of the suspension systems. In this paper a geometric configuration of a rear suspension that fits a chosen target curve is obtained. The procedure followed in this study begins by choosing the topology of the rear suspension system. After that, the rear suspension characteristics are selected (highest and lowest force, progressiveness, squat ratio…). Subsequently, user-defined functions are used to obtain the position of each suspension element along the path and, later, to get the forces at each point of the system. Finally, a genetic algorithm is used to obtain an appropriate geometry of the rear suspension elements which fits the given requirements. An example is included to demonstrate the behavior and potential of the method. This strategy takes into account both the progressiveness and desired squat-ratio of the system, which have never been included in a rear suspension design before.

Key words: Suspension system, optimization, genetic algorithm, target curve.

1 Introduction

In a roadrace motorcycle, keeping the tires in contact with the road is the main priority. This is achieved by maintaining the best motorcycle suspension setup regardless of road and load conditions. Apart from the mentioned purpose, suspension is also designed to isolate the bulk of the motorcycle from vibration and impact loads and to provide rider comfort. For these reasons, motorcycle suspension design is one of the most critical aspects in the design of the whole motorcycle.

After the engine, suspension is the most expensive system of a motorcycle. Because of this, rear suspension is rarely modified. Many papers about motorcycle suspension focus only on preload or damping adjustments of the monoshock and the fork [1][2][3][4].

In this paper, a method to modify the rear suspension geometry by changing its elements (except the monoshock) is presented. The method is based on the four-bar mechanism synthesis, since rear suspension can be treated as 2 connected 4-bar mechanisms. However, the link length optimization is different from typical methods, which try to adjust the lengths to achieve a certain path or a displacement function between several points [5][6][7]. In this case, the variables are adjusted in order to achieve a suspension curve, which will be determined by several points (vertical wheel force-angle of the swingarm) and the progressiveness of the curve. A progressive rate curve makes the load on the rear wheel to increase progressively as the wheel travel increases [8][9]. Thus, progressiveness is defined as the area between the linear suspension and the obtained curve.

Design targets of this mechanism synthesis are different from typical ones. Hence, a different method is required. The optimization method is based on the application of a genetic algorithm to the mechanism synthesis problem [10][11][12].

Hwang and Shih [13] already proposed a method for the optimization of a suspension mechanism based on the constrained flexible polyhedron method. This method is very sensitive to the initial guess and only takes into account the leverage ratio points for each position of the swingarm. In contrast, in this case a highly robust method is introduced which can introduce several restrictions (not only leverage ratio). Progressiveness has been defined and can be used as a restriction. Furthermore, the position of the whole motorcycle is corrected to achieve a higher accuracy.

This paper is organized as follows. In Section 2 there is a brief discussion about rear suspension types, whose characteristics are also described. These characteristics are the design targets and configuration accuracy is evaluated by means of the objective function, presented in Section 3. The evolutionary algorithm used to solve this problem is explained in section 4. In Section 5 an example of the whole method can be found. Conclusions are drawn in Section 6.

2 Rear suspension system characteristics

This article is focused on the design of a rear suspension with a swinging arm and a four-bar linkage. The described method can be applied to any of the existing four-bar topologies [8][14]. Nevertheless, it is advisable to know the general characteristics of each type before choosing one of them. Furthermore, if it is a commercial motorcycle, it may be necessary to use the same configuration as the original one.

Three main parameters are selected to define the suspension curve (see Fig. 1). For simplicity, vertical force in the rear wheel is represented along the vertical axis and the displacement of the shock absorber is represented along the horizontal axis.

In the example included in section 6, the first of the selected parameters is the highest force on the rear wheel, which depends on the weight of the driver and the motorcycle, among others. The highest force on the rear wheel appears when the maximum acceleration is achieved (limited by the driving traction coefficient or by wheeling). Usually, the maximum acceleration limit is given by the wheeling limit. In that case, the total weight of the motorcycle and the driver are transmitted to the ground by the rear wheel.

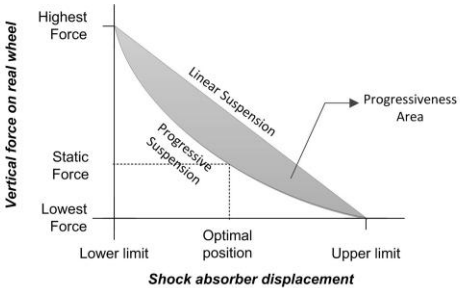

Fig. 1 Suspension target curve

The second parameter is the static force on the rear wheel (which is influenced by the COG position and total weight) when the position of the swing arm (and therefore displacement of the shock absorber) is optimal according to the desired squat ratio (Eq. 1), which is the ratio between the moment generated by the load transfer and the moment generated by the sum of the chain force and the driving force [8][9], (Fig. 2):

$$Squat-ratio \equiv \mathfrak{N} = \frac{N_{rd} \cdot L \cdot \cos\ \phi}{S \cdot L \cdot \sin\ \phi\ + T \cdot L \cdot \sin\ \phi - \eta} \qquad (1)$$

Dynamic load transfer N_{tr} is directly proportional to driving force S and height h of the COG, and inversely proportional to wheelbase p.

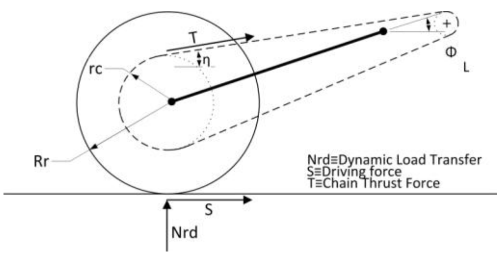

Fig. 2 Squat forces

If $\Re$ is a known value, the optimal position of the swingarm(ϕ) can be obtained. The position of the swingarm is equal to the length of the shock absorber, so the point on the suspension curve is completely defined.

The third selected parameter is the progressiveness. A progressive suspension is characterized by an increase in stiffness with displacement. Progressiveness is measured by the integral between the linear and the progressive suspension curves. This progressiveness measurement is new, so there are no reference values by any other authors. Reference values may be obtained by looking for progressiveness limits (highest and lowest areas that can be successfully optimized).

This set of parameters can be modified or even increased with other parameters. The following parameter combinations are possible: 3 force-displacement points (upper and lower limits and intermediate), 2 force-displacement points (upper and lower limits) and progressiveness, 1 force-displacement points (intermediate points), upper force limit and progressiveness.

In the example, the selected combination is 1 force-displacement point (intermediate point), upper force limit and progressiveness, so there is one dof and multiple configurations of the rear suspension are possible.

In motorcycle racing, a basic rule for the design of suspension systems is that the difference of height between the unloaded motorcycle (completely spread out suspensions) and the loaded motorcycle (with the pilot in driving position) is around a standard value. This rule establishes two force-displacement points.

3 The objective function

This function gives an assessment of the quality of the geometric configuration based on the target curve. The lower the value of this function, the better the configuration. The function has three terms (Eq. 2):

$$error = \left[f_{MAX} - f_{MAX,0} \right]^2 + \left[f_{OPT} - f_{OPT,0} \right]^2 + \left| AREA - AREA_0 \right|^{1.33} \tag{2}$$

The first term compares the obtained highest force (f_{MAX}) on the rear wheel with its reference ($f_{MAX,0}$) This force is calculated by applying the highest force of the spring when the shock absorber is completely compressed. The second term compares the obtained optimal force (f_{OPT}) with its reference ($f_{OPT,0}$). This force is calculated by applying the force which corresponds to the displacement of the shock absorber when the position of the swing arm is optimal. The last term compares the progressiveness area (AREA) to its reference ($AREA_0$). This area is calculated by integration.

The objective function is applied when the suspension curve is determined. The first step to obtain the suspension curve is to calculate the position of each element of the mechanism for each position of the swing arm and to evaluate if the current geometry is valid. The suspension is a four-bar linkage (Fig. 3).

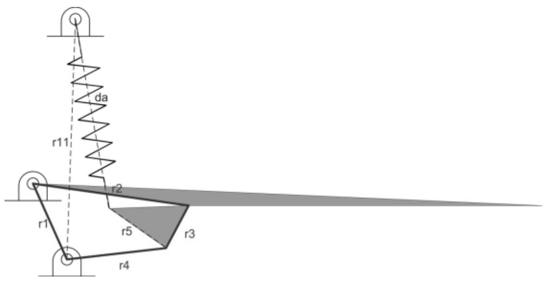

Fig. 3 Suspension as a four-bar linkage

The first task is to verify that all the lengths of the suspension elements are positive. Subsequently, the limits of movement of the swing arm will be obtained. The limits are either based on suspension geometry limits (Grashof's Law) or on interference limits. The position of each element is obtained by applying geometry and trigonometry (Fig. 4). If the calculated range of the length of the shock absorber unit is higher than the real range, the configuration is valid, and vice versa.

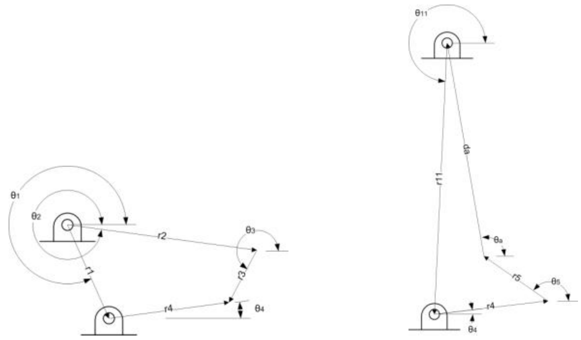

Fig. 4 Suspension sketch

The second step to obtain the suspension curve is to calculate and apply the correction angle. Since the previous positions of the elements were calculated for a fixed position of the chassis, in this step the movement of the chassis is considered and the angles are corrected (Fig. 5).

Finally, the third step is the calculation of forces. For each position, there is a set of 6 linear equations and six unknown forces. These equations come from the equilibrium of forces and moments in the triangle and the swing arm. The vertical force on the rear wheel f_r is further used in the objective function. With the last step, the suspension curve has been calculated and it can be compared with the target curve by applying the objective function.

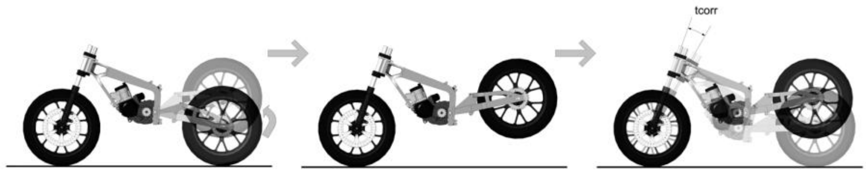

Fig. 5 Correction angle

4 Genetic algorithm

Genetic algorithms are applicable to a wide range of problems; they do not need much tailoring for specific problems and provide good solutions within an acceptable time limit. These are the reasons why a genetic algorithm has been chosen to solve this optimization problem [15].

The design variables are the lengths of the suspension elements. The constraints have been discussed in section 2 (upper force limit, squat-ratio force-displacement point, progressiveness). The objective is to set the variables to fulfill the constraints. The genetic algorithm program has been modified from standard one [9]. In this algorithm, the optimization is made based on the five best members of the initial population instead of only the best member. This modification involves the application of the standard method for each of the five best members of the original population. The reason for this modification is to avoid finding an unavailable member repeatedly when the number of restrictions is below the limit (if the best member of the initial population is always in a range, the method can obtain the same result despite running it several times). An unavailable member is a member that causes interference between any motorcycle elements along the suspension path.

The method has four main steps. The first step is the creation and evaluation of the population. With this aim, the range of the variables is defined (the initial range for the variables, the method is not restricted and the variables can exceed the range when modified by means of genetic algorithm operations). After that, a random population is generated and modified if any of the members are not valid. The five best members are also selected.

The second main step consists of verifying the finishing criteria: the number of iterations is under the limit of iterations and the best member objective function value is allowed over the maximum error.

The third step is the genetic algorithm itself. The operations which are carried out are member selection, crossover and mutation.

The last step modifies the previous population with the new calculated population. The valid members, which improve the value of the objective function with respect to the previous members in the same position, replace the old members.

The four described steps improve the population in each iteration, obtaining valid configurations of the rear suspension system when the method has finished.

5 EXAMPLE

The optimization algorithm has been used with different chassis configurations, different target curves (different restrictions) and different topologies. The obtained results have always been successful. The Pro-Link type has been selected for this example.

The finishing criteria are that the number of iterations is below 200 and the limit of the objective function value is above 2000 (maximum error in forces below 45 N, maximum error in progressiveness below 300).

Table 1 shows valid configurations with different progressiveness. Fig. 6 shows the suspension curve of configuration 6 of the table (target Area=12000).

Table 1. Configurations of the rear suspension

Config.	*AREA*	*r3*	*r4*	*r5*	*r6*	Obj. fun
1	2064	33.59	104.29	52.36	45.08	770
2	3982	35.64	95.19	43.64	39.40	888
3	6049	56.24	75.43	52.23	62.47	594
5	8121	64.04	64.22	48.21	59.46	826
6	9842	74.02	53.07	49.86	70.16	853
6	11773	74.04	49.77	55.92	40.59	410

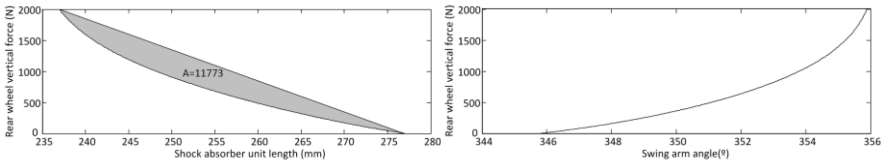

Fig. 6 - Configuration 6 curve

6 Conclusions

In this paper, an innovative method to determine the parameters of motorcycle suspension systems is presented. The method is based on the use of genetic algorithms to achieve a suspension target curve, which can be characterized by squat ratio, progressiveness or force-displacement points among others.

This method is useful to obtain any wanted rear suspension curve (if possible). This curve is static, and the effects of damping are not taken into account. As future work this aspect will be studied. The versatility of genetic algorithms allows introducing any possible restriction combination. The modifications made to the algorithm improve its performance and guarantee finding a valid solution.

The results obtained with this method have been put into practice in a racing motorcycle and have always fulfilled the restrictions of the method.

Suspension configuration has a high influence on the behavior of the motorcycle and rear suspension elements are easy and cheap to manufacture.The described method can be applied to any type of motorcycle, including commercial models. This implies that the designer can adapt the suspension to the needs of the user in a few steps. Suspension elements can be designed to achieve a certain progressiveness and/or squat ratio.

References

1. F. Baronti, F. Lenzi, R. Roncella, R. Saletti, O. DiTanna, "Electronic Control of a Motorcycle Suspension for Preload Self-Adjustment," IEEE Trans. on Industrial Electronics, pp.2832-2837, vol.55/7, Jul 2008.
2. V. Cossalter, A. Doria and R. Lot, Optimum suspension design for motorcycle braking, Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility 34 (2000), pp. 175–198.
3. V. Cossalter and R. Lot, A motorcycle multi-body model for real time simulations based on the natural coordinates approach, Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility 37 (2002), pp. 423–447.
4. Trevitt, A.: Sportbike Suspension Tuning: How to Improve your Motorcycle's Handling and Performance, USA, 2008.
5. R R.J. Loerch, A.G. Erdman, N. Sandor, A. Mihda, Synthesis of Four Bar Linkages with Specified Ground Pivots, Proceedings of 4th Applied Mechanisms Conference, Chicago, 1975, pp. 101–106.
6. C. Han, A general method for the optimum design of mechanisms, Journal of Mechanisms (1966), pp. 301–313.
7. S. Krishnamurty and D.A. Turcic , Optimal synthesis of mechanisms using nonlinear goal programming techniques. Mechanisms and Machine Theory 27 5 (1992), pp. 599–612.
8. Cocco, G.: Motorcycle design and technology, USA, 2004.
9. Cossalter, V.: Motorcycle dynamics, Italy, 2006.
10. J.A. Cabrera, A. Simon and M. Prado, Optimal synthesis of mechanisms with genetic algorithms, Mechanism and Machine Theory 37 (2002), pp. 1165–1175.
11. A. Kunjur and S. Krishnamurty , Genetic algorithms in mechanical synthesis. Journal of Applied Mechanisms and Robotics 4 2 (1997), pp. 18–24.
12. R. Storn and K. Price , Differential evolution. A simple and efficient heuristic scheme for global optimization over continuous spaces. Journal of Global Optimization 11 (1997), pp. 341–359.
13. Hwang, Wen-Miin Shih, Jau-Min, Optimal Synthesis of Suspension Mechanism with Variable Leverage Ratio for Motorcycle, Journal of the Chinese Society of Mechanical Engineers, 1987 Vol. 8 No. 1 043-050.
14. Foale, T.:Motorcycle handling and chassis design: the art and science, Spain, 2006.
15. Eiben, A.E. and Smith, J.E.: Introduction to evolutionary computing, Germany, 2003.