Railway Suspension system Optimization

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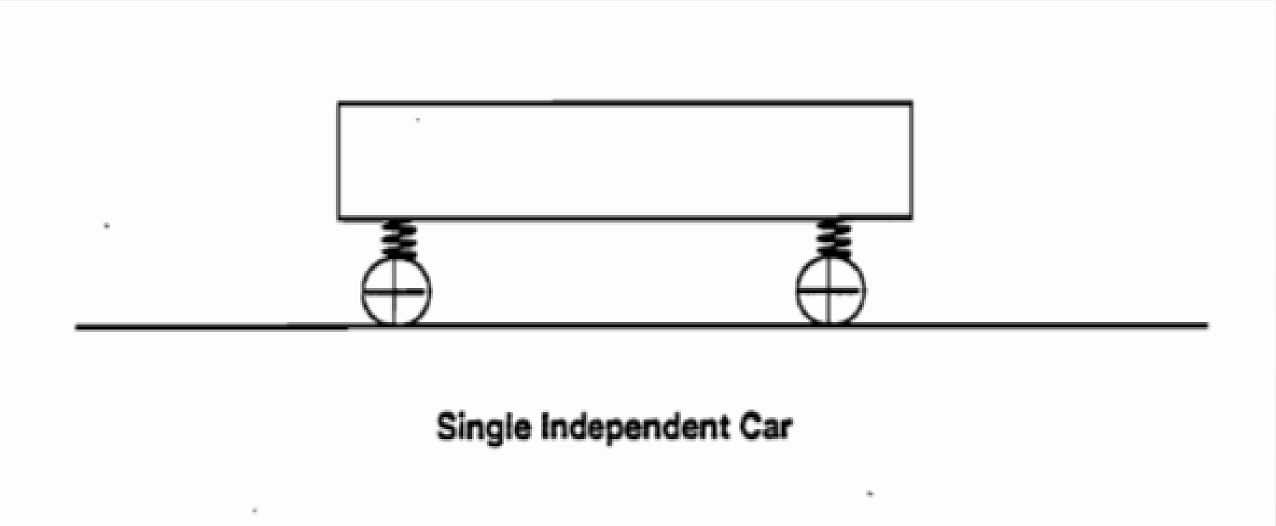
Suspension system in Rail Coaches

- There are various configurations in which suspensions are used in Railway depending on the era, country speed of train etc.
- But most of the rail coaches have the concept of dual suspension systems: Primary and Secondary.
- Primary Suspension is employed between the wheel set and the axle.
- Secondary Suspension is employed between the Car(bogie) body and the wheel set.

Suspension system in Rail Coaches



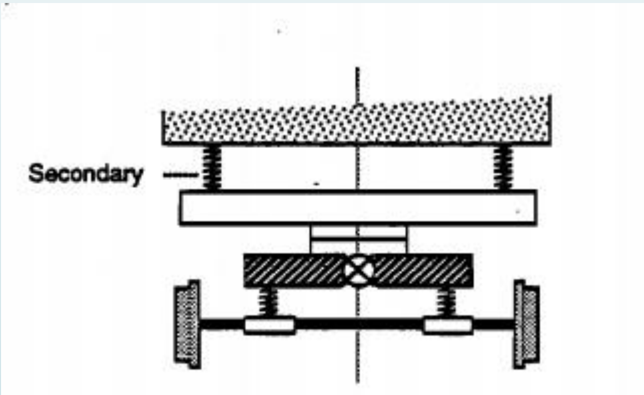


Image Courtesy: Reference [3]

Primary suspension

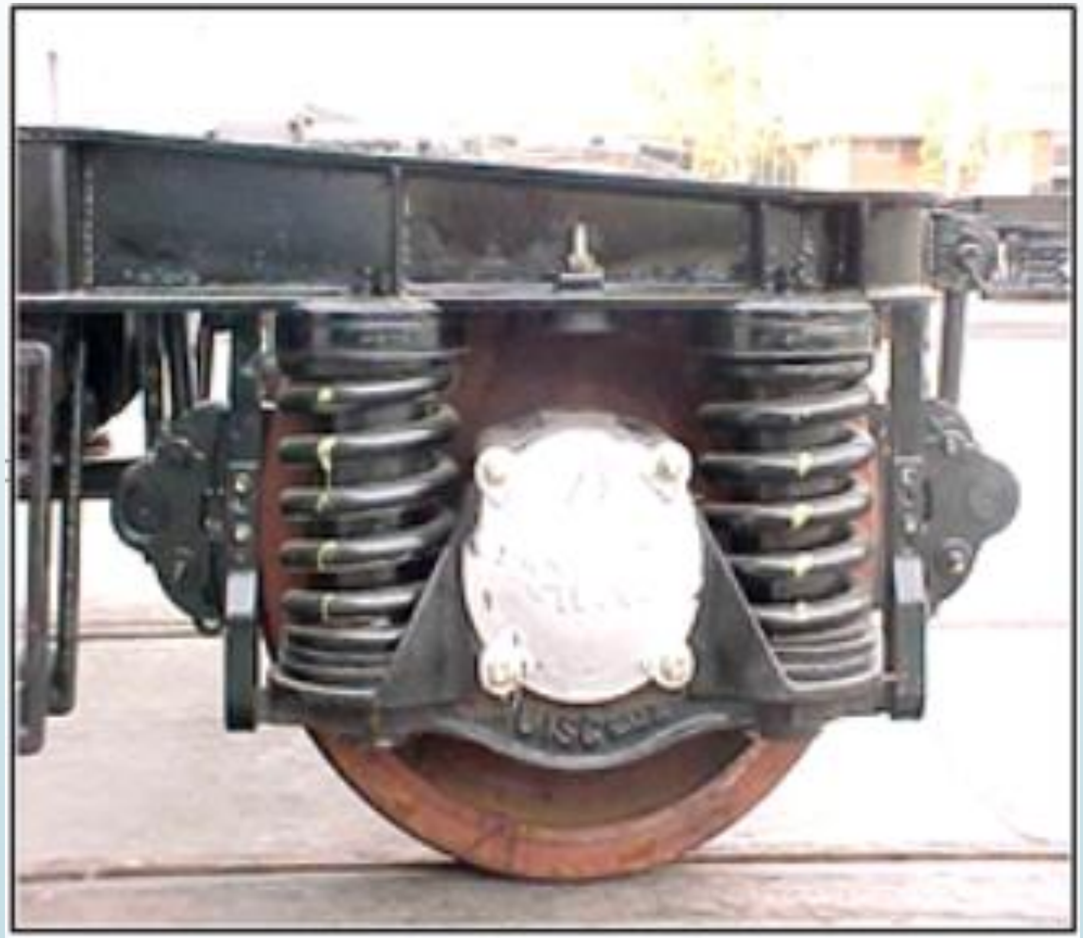
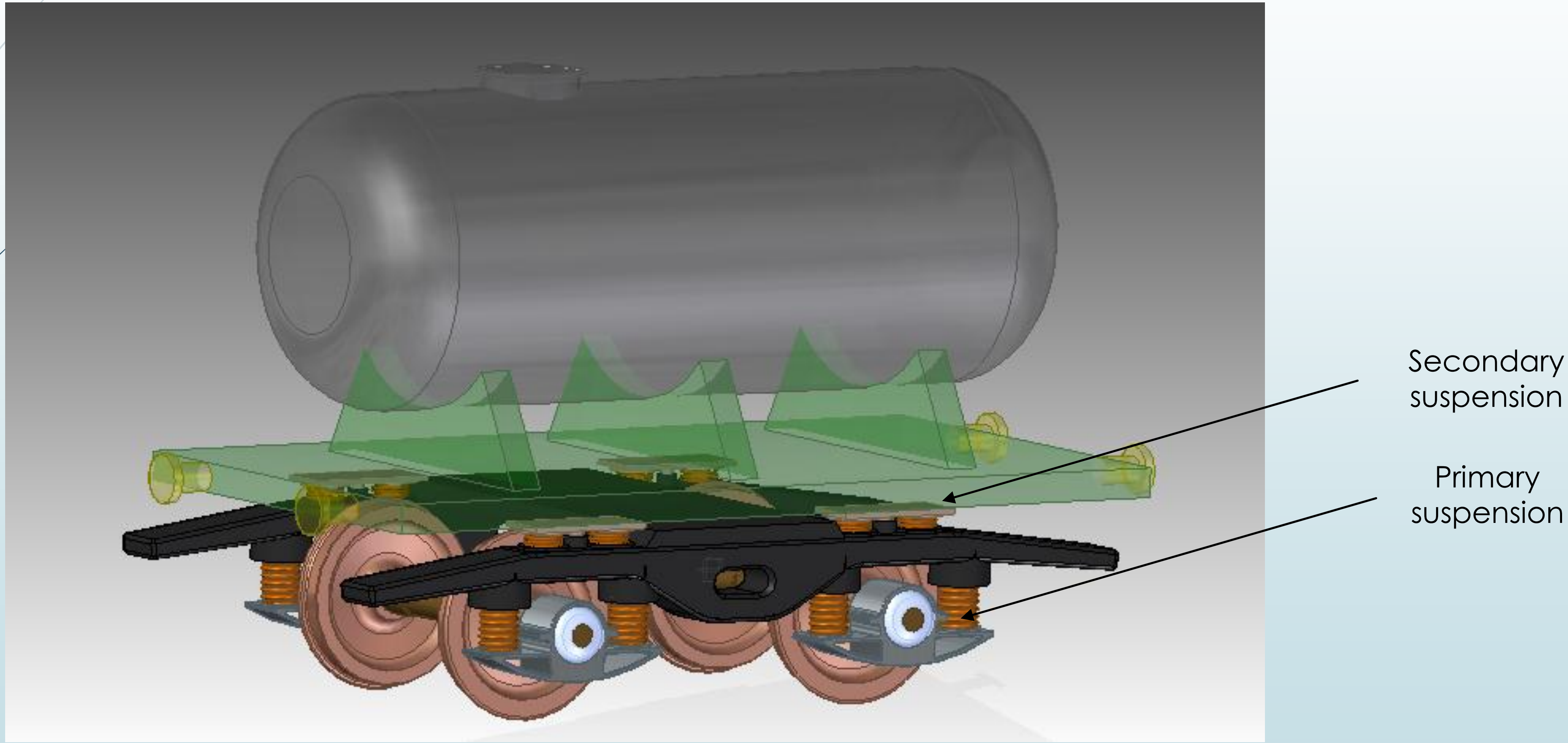


Image Courtesy: http://4.bp.blogspot.com/-KwWbwFOfoe0/VbG6LDYPhPI/AAAAAAAADls/HoSMyvogb68/s640/PRIMARY.PNG

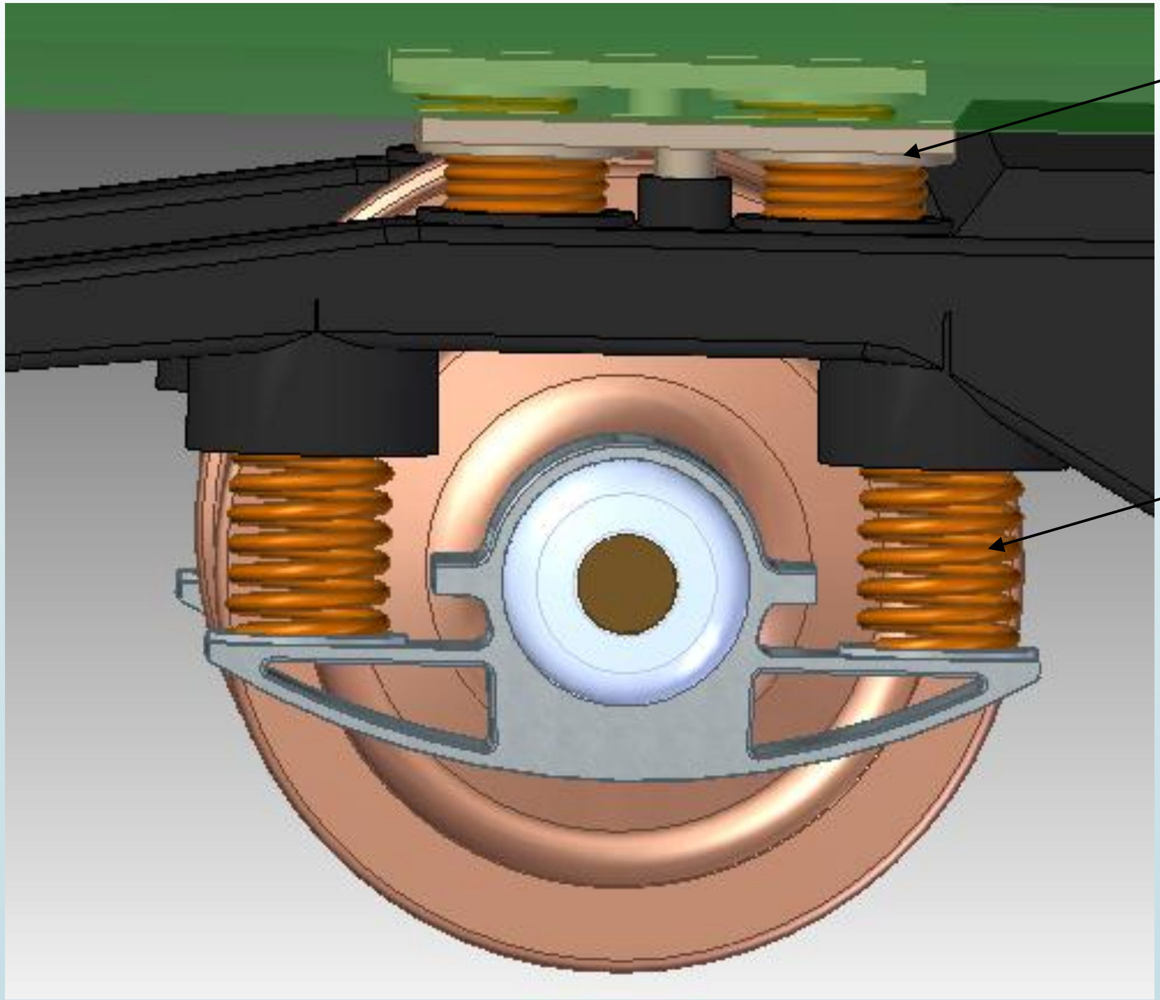
Secondary Suspension

Image Courtesy: http://sonicstorm.com/trains/secondary.jpg

Model of the Bogie



Model of Primary and Secondary Suspensions



Our Aim

- Our aim is to maximize the Ride comfort.
- We have chosen the Ride comfort index as defined by German researchers Sperling and Betzhold for Rail Cars.
- The Wertungszahl (W_z) Index is defined as

$$W_z = [100\, B(f)\, a_0]^{.3}$$

Where, a_0 is the acceleration amplitude (m/s2) at floor level in the lateral or vertical direction and B(f) is the frequency weighting function.

- The above equation indicates that The W_z Index is proportional to a_0 which means that to minimize the W_z index we need to minimize the Force function F_z.

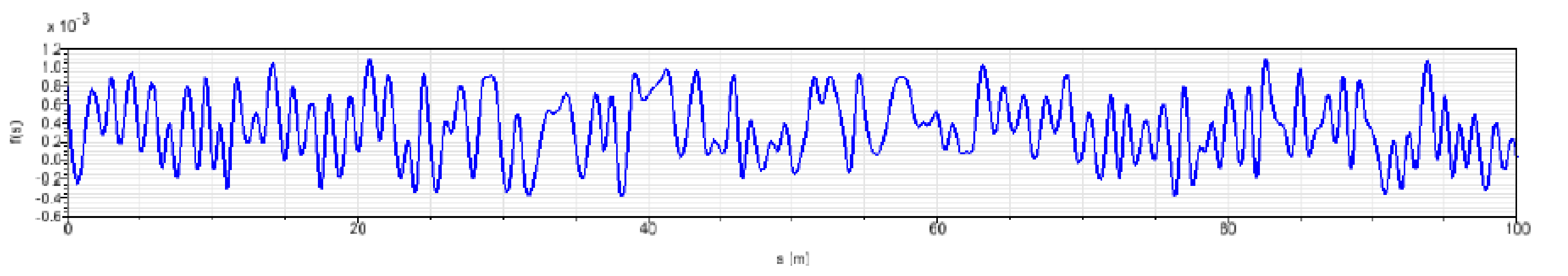
Wertungszahl (W_z) Index : Comfort level

Ride Index Wz	Comfort level
1	Just noticeable
2	Clearly noticeable
2.5	More pronounced but not unpleasant
3	Strong, irregular, but still tolerable
3.25	Very irregular
3.5	Extreme irregular, unpleasant
4	Extremely unpleasant. Harmful

Note: Figure taken from Reference [1]

Assumptions made

- The model has been simplified so as to fit the Quarter car model.
- The Wheel has been assumed to be rigid and the previously used parameters for the tire are now used for the Primary Suspension
- The following graph represents typical track irregularities along the length of the track.



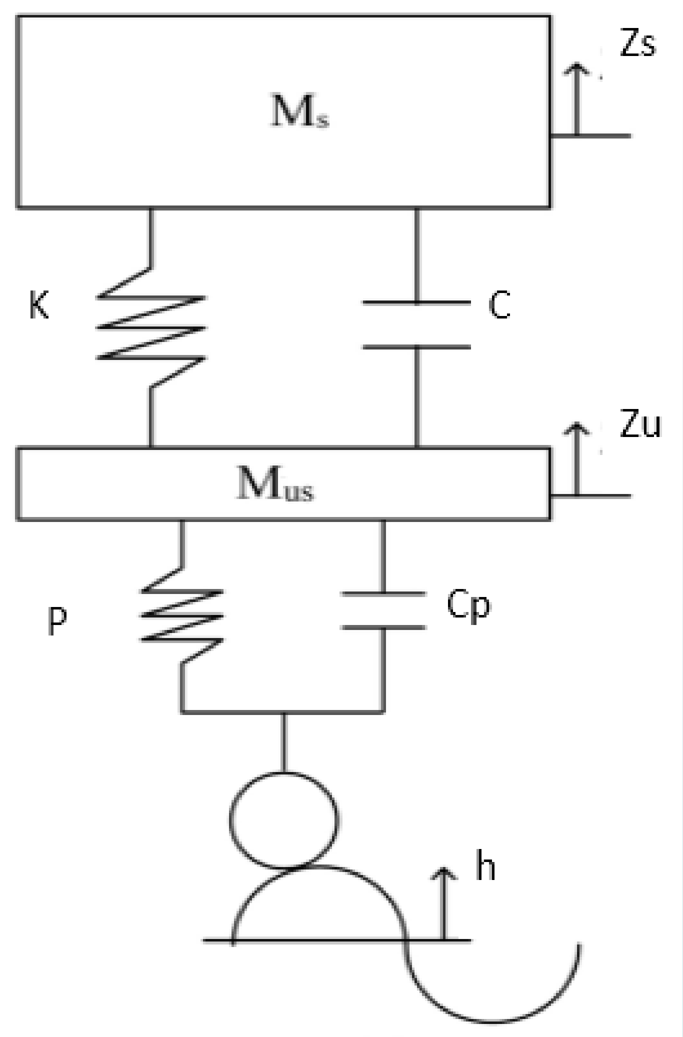
- So we have used an approximate function $h = h_0(e^{i\omega t})$ where h_0=10^{-4} m as shown in the graph above and ω=50 Hz.

Note: Figure taken from Reference [1]

Suspension Parameters

Selected Bogie type is Buckeye G70 manufactured by Amtrak

- For Primary suspensions:
  - Spring Stiffness P=180*10^6 N/m.
  - Damping rates range Cp=89-250 *10^3 Ns/m
- For Secondary suspensions:
  - Spring Stiffness k=728*10^3 N/m.
  - Damping rates range C= 30-200 *10^3 Ns/m.



Equation of motions

- $Ms * \ddot{Z}_s + C(\dot{Z}_s - \dot{Z}_u) + k(Z_s - Z_u) = 0;$ (1)
- $M_u * \ddot{Z}_u + C(\dot{Z}_u - \dot{Z}_s) + k(Z_u - Z_s) \;\; + C_p(\dot{Z}_u - \dot{h}) + P(Z_u - h) = 0;$ (2)

The aim here is to minimize the force function i.e. $F_z = -P(Z_u - h)$ where Fz is The vertical force exerted by the track on the wheel.

The parameter Cp cannot be ignored now since it does not represent the tire parameters anymore but represents primary suspension. So simplified method of ignoring Cp cannot be used.

We have used ode45 solver to solve these equations for a range of values of C and Cp and thereafter applied Genetic Algorithm to find their optimized values.

Equation of motions

For ode45 following 1st order form of the above equations are used:

- $Z_s = Z_1$;
- $\dot{Z}_s = \dot{Z}_1 = Z_2$;
- $\ddot{Z}_s = \dot{Z}_2$;
- $Z_u = Z_3$;
- $\dot{Z}_u = \dot{Z}_3 = Z_4$;
- $\ddot{Z}_u = \dot{Z}_4$;

Equation of motions

- $M_s\dot{Z}_2 + C(Z_2 - Z_4) + k(Z_1 - Z_3) = 0;$

$$\dot{Z}_2 = \left(\frac{-1}{M_s}\right)\{C(Z_2 - Z_4) + k(Z_1 - Z_3)\};$$

- $M_u\dot{Z}_4 + C(Z_4 - Z_2) + k(Z_3 - Z_1) + C_p\left(Z_4 - \dot{h}\right) + P(Z_3 - h) = 0;$

$$\dot{Z}_4 = \left(\frac{-1}{M_u}\right)\{C(Z_4 - Z_2) + k(Z_3 - Z_1) + C_p\left(Z_4 - \dot{h}\right) + P(Z_3 - h)\}$$

Final Equations of motions

- $\dot{Z}_1 = Z_2;$
- $\dot{Z}_2 = \left(\frac{-1}{M_s}\right)\{C(Z_2 - Z_4) + k(Z_1 - Z_3)\};$
- $\dot{Z}_3 = Z_4;$
- $\dot{Z}_4 = \left(\frac{-1}{M_u}\right)\{C(Z_4 - Z_2) + k(Z_3 - Z_1) + C_p\left(Z_4 - \dot{h}\right) + P(Z_3 - h)\}$

The following values were used for various other coefficients and parameters

- Bogie Mass= 51000 kg
- Quarter Wt on one wheel= 12750 kg (Sprung Mass)
- Wt of suspension, wheel set(quarter),axel etc= 2000 kg(Unsprung Mass)
- P and K have been fixed while Cp and C have been made as parameters for optimization.

Optimization Approaches

Optimization Goal : Minimizing Fz for given input h

Heurisitc Methodologies

Genetic Algorithms , Artificial Neural networks , Fuzzy Logic

Iterative methods

Quasi-Newton method , Gradient descent method, Interpolation methods

Genetic Algorithms chosen

- Random Global Search Algorithm
- Multiple local optima
- The objective function is not smooth
- The number of parameters is 2

Genetic Algorithm

Length of chromosome = 12+12 = 24
Size of chromosome population = 20
Cross-over probability = 0.7
Mutation probability = 0.001
Fitness function = Fz
Termination Criteria : Either 1000 iterations or no improvement in solution quality after 200 generations

ODE45 is used to solve the set of differential equations for quarter car model.
ODE45 uses 4th Order Range-Kutta method

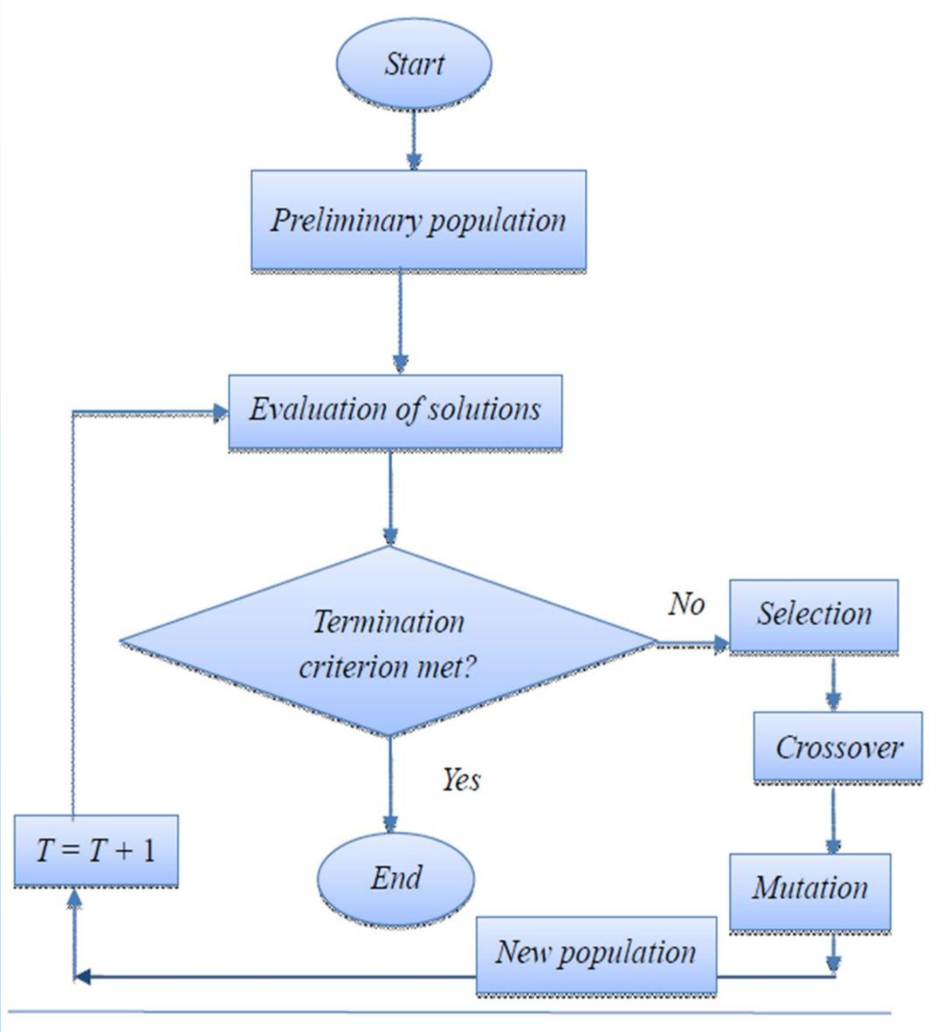
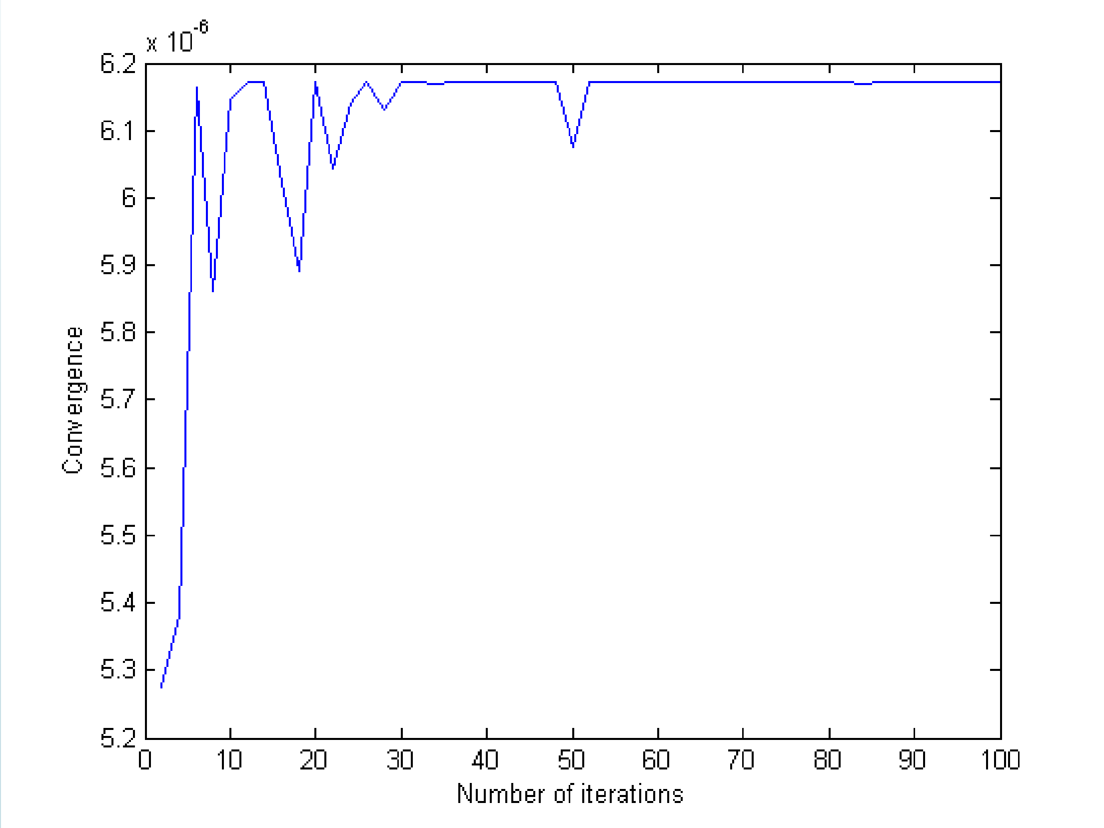


Image Courtesy:
http://file.scirp.org/Html/1-8302163%5C4922370b-3e66-41cb-93e7-51d0cc0e30f9.jpg

Results

- Genetic Algorithm Convergence Graphs



Optimized values for C and Cp

The following optimized values were obtained for C and Cp

- C = 98.67 kNs/m
- C_p = 30.58 kNs/m
- When we use above values in the equations and find out the Wz index it comes out between "2-2.5" ie Clearly noticeable to "More pronounced but not unpleasant" range.

References

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Thank You