

Abstract

Metro trains have complex dynamics when compared to normal long distance trains as they experience frequent acceleration, braking, sharp turns and steep gradients. Due to sharp turns and twists in track, metro coaches are more prone to the derailment, frictional energy loss, wear, and curve squeal noise. Metro coaches have to satisfy mutually conflicting requirements of smooth curvability on turns and running stability on straight track. Dynamics of the metro coaches are evaluated in terms of safety and ride quality parameters. Safety parameters include track shift force, derailment coefficient, maximum dynamic wheel loading/unloading ratio, and coach, bogie accelerations, whereas, ride quality parameters involve ride comfort in vertical and lateral directions. Train safety and ride quality depend on the following: (1) Track parameters including track curvature, superelevation, twist, elevation, track irregularities, track stiffness, damping, rail profile, and rail cant, (2) Vehicle parameters including mass, inertia, and centre of gravity location of wheelset, bogie, and coach, primary, secondary suspension parameters, wheel profile, power train characteristics, and brake system design, and (3) operating parameters including train speed, axle load, and friction at rail-wheel contact. Ride quality and safety are studied here for BEML coaches plying on east-west Kolkata metro track.

To improve ride quality and safety, it is essential to identify and optimize influential vehicle and operating parameters through parametric studies. To this end, multibody vehicle dynamics models need to be built and validated with field data. Field trials were conducted with a BEML coach on a newly built track in Kolkata, India. Wheel RPM, coach, bogie accelerations, and primary, secondary springs compression were continuously monitored during the tests. Trials were conducted under varying axle loads, vehicle speeds, and air spring condition. The multibody vehicle dynamics model, replicating BEML metro coach, is built in commercial software Simpack. The multibody vehicle dynamics models, for tare and crush conditions, are validated with the field trails data by matching bogie, coach mo-

tion and lateral, vertical ride comfort indices along the track. Parametric studies were done using the response surface methodology approach to identify the influential parameters and study their effect on vehicle dynamics of the metro coach. Parametric studies were done separately for identifying the role of suspension and operation parameters. Suspension parameters considered include horizontal stiffness of air spring, effective area of air spring, horizontal stiffness of primary springs, and damping coefficient of the lateral dampers. Operating parameters considered include axle load, vehicle speed, and friction at the rail-wheel contact. Results demonstrate that a significant 8% reduction in average wear index was observed for 20% reduction in horizontal stiffness of primary and secondary springs. Similarly, a reduction of around 40% in average wear index was observed for a reduction of 25% axle load. Around 20% reduction in derailment coefficient was observed as maximum friction reduces from 0.47 to 0.3 at the rail-wheel contact. Operating speed within the considered range has little effect on derailment coefficient and wear number.

To quickly assess the dynamics performance of the vehicle, data driven models can be used as an alternative to simulation models. In this study, numerous machine learning models are used for predicting the contact parameters of the coach along the track length. In order to avoid stagnation at the extremum points, meta-heuristic algorithms are used as optimizers in the machine learning models. In the first phase of work, artificial neural network (ANN) and recurrent neural network (RNN) models along with four meta-heuristic algorithms, namely, improved real coded genetic algorithm (IRGA), bonobo optimizer (BO), success-history based adaptive differential evolution (SHADE), and grey wolf optimizer (GWO) are used to predict the derailment coefficient, contact forces, contact area and lateral contact location. For this, data of a single run is used for training and test. In the second phase of work, a large dataset was created from 18 runs. In this phase of work, to improve the accuracy of the machine learning models, a deep neural network (DNN) model was used. Particle swarm optimization (PSO) algorithm was used as the optimizer. Derailment coefficient and wear index of all eight wheels of the coach were predicted using the DNN models. The DNN model trained on the large dataset gave the lowest error (MAPE less than 2%) on test for derailment ratio and wear index, despite being provided with fewer number of inputs. This is in spite of the fact that the test data considered for the DNN model was larger and covered a wide parameter space. Additionally, no fictitious peaks were observed in predictions from the DNN model. The developed DNN model could be used as an alternative for condition monitoring and fault detection.

Keywords: Field trials, multibody vehicle dynamics model, parametric study, machine learning models, safety, ride comfort.