Journal of Emerging Technologies and Industrial Applications
Vol. 3 No. 1 (2024) pp. 1-3
e-ISSN: 2948-507X

Journal homepage: https://jetia.mbot.org.my/index.php/jetia/index

Review on Davis equation and railway operation power consumption, impact to railway technologies and industrial application

Nur Shahibrahim Mahamudin *[1]

[1]Dept. Of Mechanical and Aerospace Engineering,
Kulliyah of Engineering (International Islamic University Malaysia), Selangor, MALAYSIA

Email: [a]nshahibr1@gmail.com

Abstract: Davis Equation is a governing equation that widely use in railway application to describe the total resistance acted on running train. Train resistance compromise major percentage of overall train traction power losses and it gives large impact to train performance and operation power consumption. Davis equation is compromise of three components of train resistances that effect the train motion in many aspect such as train loading, track coefficient of friction and aerodynamics. Several technology had being implemented on nowadays industrial application in term of these three Davis equation components and had successfully reduced approximate 3% to 25% of operation power consumption.

Received 20 February 2024; Accepted 15 May 2024; Available online 26 June 2024

Keywords: Davis equation, resistance, operation power consumption

1. Introduction

Davis equation is the three component of train resistance such as the resistance component independent to train speed such as rolling and track resistance, contacts between the wheel and track surface, the resistance dependent to train speed such as flange friction, wave action and oscillation and the streamlining and aerodynamic coefficient used to define train resistance dependent on the square of the train speed such as aerodynamic resistance. Davis equation can be summarized as the running resistance, therefore it will impact the railway operation power consumption. Several technological and industrial application is develop to tackle the Davis equation for optimum and efficient railway operation.

2. Davis equation

The coefficients of the Davis equation are related to different resistance components and train resistance can be expressed in following form [1][2],

$$R = A + Bv + Cv^2 \tag{1}$$

Where R is the train resistance in N, A is the resistance component independent to train speed such as rolling resistance, contacts between the wheel and track surface. B is the coefficient used to define train resistance dependent to train speed such as flange friction, wave action and oscillation effect and C is the streamlining and aerodynamic coefficient used to define train resistance dependent on the square of the train speed such as air resistance. Davis equation can be generalised into the following equation [2],

$$R = (c_1^r + \frac{c_3^r}{p} + 10i + c_2^r v)G + c_a^r a v^2 \qquad (2)$$

Where the value of c_1^r is the coefficient of resistance on track surface or also can be represent as the track coefficient of friction, μ and G is the train weight or can be represent as mg. Values of c_2^r and c_3^r are the coefficient of resistance due to track alignment, p is the train axile loading in N and i is the track gradient percentage. The value of c_a^r is the coefficient of train body smoothness and the value a is the cross-sectional profile of the train frontal [2]. Therefore, by summarising the above equation (1) to equation (2) the value A, resistance component independent to train speed; rolling friction is represented in term of the following equation.

$$A = mg\mu \qquad (3)$$

Where m is the train mass in kg, The value of g is the gravitational constant. The value μ is the coefficient of friction of the running track. Value B is the coefficient used to define train resistance dependent to train speed such as alignment resistance can be represented in term of the following.

$$B = (\frac{c_3^r}{p} + 10i + c_2^r v)\ G \qquad (4)$$

The value i is the percentage of track gradient. In addition, G is the train weight multiply by the gravitational constant and the value v is the train speed. Meanwhile, the value C is the streamlining and aerodynamic coefficient can be represent in the following term,

$$C = c_a^r\ a\ v^2 \qquad (5)$$

The value a is the cross-sectional profile of the train frontal area. The value v is the rail vehicle speed. Traction force can be represented in the following equation,

$$T_E\ (v) = 2650\ \frac{P}{V}\ \eta \qquad (6)$$

Where P is operation power consumption in hp and η is the electrical propulsion system efficiency range between 0.78 to 0.84 for each railway system. Davis equation can be related to operation power consumption in term of the following net force equation,

$$\sum F = T_E\ (v) - R(v) - B_e(v) = ma \qquad (7)$$

Where $\sum F$ is the net force in N, T_E is the Traction force in N, R is the Resistance force in N and B_e is the Braking force in N and value of velocity, v and acceleration, a change according to the region of the station-to-station travel.

3. Operation power consumption

Based on the above Davis equation, the effect of train loading m, track coefficient of friction μ and aerodynamic stremline C impcat the operation power consumption.

3.1 Train Loading

Reduction of train loading had bring a large impact to train resistance hence reducing the operation power consumption. According to a research at Yizhunag Line China, 50% reduction in train loading reduced approximate 50% of operation power consumption [3].

Technological and industrial application had well develop on this area. For example, Siemens had developed a new SF7000 bogie design for the new Desiro city emu. The design is 25% lighter than the traditional bogie [5] and expected to reduce 25% of operation power consumption.

In addition, the application of boarding space division (BASD) technology to regulate passenger movement during train boarding process had lower the train loading by regulating the boarding time [4]. In railway logistic technology, the regulation of train loading can be achieve by determine the most suitable mode of freight shipping procedure whether using blocks or units. Operation power consumption can be reduced between 5% to 25% by applying the suitable mode based on the shipment size and turnaround [6].

3.2 Track coefficient of friction

Normal operation condition of railway track coefficient of friction can be as low as µ 0.05 in ice and snow condition and can be as high as µ 0.7 [2]. A research at China metro line shows 20% reduction track friction reduced approximate 3% of operation power consumption [3]. Lower track coefficient of friction had reduced the resistance in Davis equation hence reducing the operation power consumption.

In technological and industrial application, two ways to commonly used to reduce this value is by using the track lubrication and rail griding technology. Rail lubrication is a process of applying grease to running track and rail grinding is a process of grinding running track to improve track profile and to ease track corrugation[7][8]. Indirectly, these two process will reduced the track coefficient of friction hence reducing operation power consumption. According to a research on top of rail friction modifier using rail lubrication, average of 5.3% and 7.8% reduction of operation power consumption is recorded in the research for curve and tangent railway track [9]. In addition, rail grinding technology had proven to improve train wheel and track interaction for smooth, safe and efficient railway operation.

In addition, Maglev or magnetic levitation train technology; floating train operation that move with the interaction of electromagnetic attraction and repulsion, aims is to reduce the impact of track resistance and

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index

friction. A research by Stanford University shows that operation cost of Maglev train is only 3 cents per passenger mile compared to 15 cents per passenger mile in conventional train operation [10].

3.3 Train aerodynamic

Advance aerodynamic technology has been adopted to nowadays train design. Good train aerodynamic design is important because the influence of the value of *C* in Davis equation increases with square of the train speed [11]. Therefore, for a high-speed rail operation, the impact of aerodynamic resistance is bigger compared to freight and urban train operation.

In 2010, Bombardier transportation had set a new benchmark in low aerodynamic resistance train design by introducing the ZEFIRO train set. The design had successful reduced 25% of aerodynamic resistance and 15% of operation power consumption [12]. Since then, the Arrowedge technology; train design with tapered body to reduce aerodynamic resistance is introduced not only in high-speed application but also in freight and urban train operation.

4. Conclusion

In conclusion, Davis equation have bring significant impact to operation power consumption in term of train running resistance. Three aspects that related to Davis equation that affect the operation power consumption is the train loading, track coefficient of friction and train aerodynamic. Several technology and industrial application such as rail grinding and lubrication, maglev and Arrowedge technology have successfully reduced 3% to 25% of operation power consumption. As railway technology is evolving, the industrial application of new technology to reduce operation power consumption is important for rail operator to reduce their operation cost and expenditure. Therefore, by focusing in this three aspect of Davis equation, a more efficient railway technology application can be develop.

Acknowledgement

I would like to thanks people who share and contribute to this review.

References

[1] Hansen, H. S., Nawaz, M. U., & Olsson, N. (2017). Using operational data to estimate the running resistance of trains. Estimation of the resistance in a set of Norwegian tunnels. Journal of Rail Transport Planning & Management, 7(1), 62-76.

[2] Vukan, R. (2007). Urban Transit Systems and Technology, John Wiley & Sons.

[3] Shuai Su, Tao Tang and Yihui Wang (2016). Evaluation of Strategies to Reducing Traction Energy Consumption of Metro Systems Using an Optimal Train Control Simulation Model.

[4] Sonia (2012). Passenger Boarding/Alighting Management in Urban Rail Transportation.

[5] Fender, K. (2012, March 16). Siemens presents new lightweight bogie. International rail journal. https://www.railjournal.com/rolling-stock/siemens-presents-new-lightweight-bogie

[6] Culver, M. (2020, October 13). 10 rail logistics cost reduction strategies. https://www.rsilogistics.com/blog/strategies-to-reduce-rail-transportation-cost

[7] M. Ishida, T. Ben, F. Aoki (2006). The effect of Lubrication on Vehicle/Track Interaction and Performance of Friction Moderator.

[8] Innotrack (2006). D4.5.5- Guidelines for Management of Rail Grinding.

[9] VanderMarel, J., Eadie, D. T., Oldknow, K. D., & Iwnicki, S. (2014). A predictive model of energy savings from top of rail friction control. Wear, 314(1), 155-161.

[10] Ilonidis. S. (2010). Maglev energy budget.

[11] P Rochard, B., & Schmid, F. (2000). A review of methods to measure and calculate train resistances (Vol. 214).

[12] Turner, J. (2013, November 4). Resistance is futile: how aerodynamic inform train design. https://www.railway-technology/feature/feature-aerodynamic-train-design-arrowedge-union-pacific-bombardier-zefiro

Published by MBOT Publishing
https://jetia.mbot.org.my/index.php/jetia/index