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RETARDER CONTROL ALGORITHMS OF KÖNIG, WONG, AND WABCO

I Introduction

One of the stated objectives of this project is to evaluate existing algorithms that are currently being used to control retarders in class yards to see if the performance of existing (or new) yards might be improved by using better algorithms. The first step toward this objective should be an exhaustive study of the existing algorithms. This note is intended as part of that first step. In particular, retarder control algorithms described in König's 1969 paper[1] and those used by WABCO (as revealed in their patents[2,3]) are described. Two algorithms proposed by Peter Wong[4,5] are also described.

The König paper is important because it appears to represent the best of the algorithms then in use in Europe (1969). WABCO is one of the two major suppliers of class yard equipment in the United States. Future notes will describe algorithms used by GRS (the other major U.S. supplier) and various other algorithms. Following that, the algorithms will be critically evaluated and compared. Optimum and/or improved algorithms will then be selected.

II Categories of Algorithms

For the sake of simplicity, I propose that retarder control algorithms be separated into the following categories based on what task the algorithm is intended to perform, rather than how the task is performed:

- Master and Group Retarder Algorithms.

  These algorithms are used to control the master and/or group retarders in a conventional class yard. Inputs to these algorithms typically

- consist of car velocities (from doppler radar, for example), car presence signals (from wheel detectors) predicted rolling resistance of the car, and cut list information (often from a central computer). The output of the algorithm is a "desired exit speed" from the retarder(s) being controlled.
- Tangent Point Retarder Algorithms.
  These algorithms are used for the control of tangent point retarders. Inputs are typically car velocities, car presence signals, predicted rolling resistance of the car, and "distance to couple" measurements. The output of the algorithm is the "desired exit velocity" from the tangent point retarder.
- Deceleration Algorithms.
  These algorithms are used to achieve the "desired exit velocity" which is the output of the above algorithms. Inputs to the algorithm are typically car weight or weight class, car velocity signals, car presence signals, and the "desired exit velocity." The outputs of the algorithm are the retarder control signals. These are typically "open" and "close" commands and heavy, medium, or light pressure commands.
- Rollability Prediction Algorithms.
  These algorithms are used to predict the rollability (or rolling resistance) of a car. This information may be used as input by the algorithms above. Inputs to these algorithms are typically car velocity and presence signals.

It should be apparent that at least one algorithm from each of the first three categories above is needed for the control of a conventional automated class yard. Some yards may also use an algorithm(s) from the fourth category. This list of categories need not be exhaustive, however. New categories may be added in the future to cover new or unconventional algorithms which do not fit into one of the present categories.

Below, several algorithms which have been found in the literature are discussed. In order to facilitate subsequent discussion and comparison of the algorithms, I have (sometimes arbitrarily) assigned a unique name to each algorithm discussed.

III Master and Group Retarder Algorithms

A. Two Delta V

This algorithm is called "2 · DELTV" by König.[6] It is similar to an algorithm which we have been calling the "Magic X." Variables are defined as follows:

V_{ein} = Car speed at the entrance to the retarder

V_m = A reference speed (equal to "the mean speed of the slowest-runner in the zone of the valley brake")

ΔV = A speed difference, see below

F = A "deflection factor" which is determined by "trial and error" for a given yard. Typically, F = 2

V_{aus} = Desired exit speed from retarder.

The exit speed is determined as follows:

$$\Delta V = V_{ein} - V_m$$

$$V_{aus} = V_{ein} - (F)\Delta V \quad .$$

B. Siemens Running Time

This algorithm is only vaguely described in the reference. Apparently it is similar in results to the above algorithm. However, this algorithm uses the running time of each car from the crest to the retarder entrance rather than V_{ein} as an input.

C. WABCO Target Time

This algorithm is described in great detail in the Budway and McGlumphy patent.[8] Basically, the retarders are controlled to achieve a certain target time for the travel of each car from the crest to several reference points along the tracks in the switching area. These target times are precomputed parameters. A different set of target times would be used if the humping speed were changed.

Variables are defined as follows:

T_T = Target time from crest to reference point below retarder being controlled.

T_0' = Measured travel time between crest and entrance of retarder being controlled.

V_E = Measured entrance speed to retarder.

V_X = Desired exit speed from retarder.

A_R = Average deceleration in the retarder.

G_3' = Average grade (equivalent acceleration) between exit of retarder and the reference point downstream.

R_3 = Predicted average rolling resistance of the car (equivalent acceleration).

S_T = Distance from the exit of the retarder to the downstream reference point.

L_R = Length of the retarder.

L_C = Length of the car.

The basic equation used by this algorithm is given in the reference.[9] In slightly simplified form the equation is:

$$T_T - T_0' = \frac{1}{V_X}\left[\frac{L_R + L_C}{1.467} + \frac{\left(V_X - V_E\right)^2}{0.219\ A_R}\right] + \frac{2\ S_T}{1.467\left[V_X + \sqrt{V_X^2 + (G_3' - R_3)S_T}\right]} \quad .$$

Making the simplifying assumptions that

$$L_R = L_C = 0$$

and

$$V_X = V_E \quad ,$$

the above equation can be rearranged to give

$$S_T = (1.467)\ V_X\ (T_T - T_0') + \left[\frac{1.467}{2}\right]^2 (G_3' - R_3)\ (T_T - T_0')^2 \quad .$$

This relation is similar to the well-known relation for uniformly accelerating motion

$$x = v_o t + 1/2\ at^2 \quad .$$

Presumably, this similarity is not coincidental, but arises because the WABCO algorithm is incorporating this well-known relationship, together with "fudge factors" and/or other coefficients.

Solution of the basic equation to determine the desired exit speed is done by iteration because a closed-form solution presumably is not available. A flow chart for the iteration procedure is given in the reference.[10]

IV Tangent Point Retarder Algorithms

A. Energy Equation Target Speed

The earliest reference to this algorithm that I have seen is a GRS patent,[11] it also appears in numerous other references.[12,13,14,15] The algorithm uses the well-known energy equation to predict the retarder exit velocity which will result in a desired coupling velocity. Variables are defined as follows:

V_C = Desired coupling velocity

V_X = Computed retarder exit velocity

R = Predicted rolling resistance of the car (in units of force)

S = Distance from tangent point retarder exit to coupling point

g = Acceleration due to gravity

Δh = Elevation change between retarder and coupling point

m = Mass of the car

The equation for V_X is then:

$$V_X = \sqrt{V_C^2 + \frac{2RS}{m} - 2g\Delta h}$$

B. Straight Line Theory

This algorithm is based on an unexplained "straight line of theory" of car behavior.[16] The parameter, K_D, is related to the rolling resistance (see VI-6 below). The desired exit speed from the tangent point retarder is computed from:

$$V_X = V_C + 0.00747\ K_D S \quad .$$

V Deceleration Algorithms

A. Retardation at Earliest Moment

König is responsible for coining the name of this algorithm,[17] but it is widely used.[18,19] The retarder is commanded to close as the car enters the retarder. The retarder is then commanded to open after the velocity of the car has reached the desired exit velocity.

B. Retardation at Last Moment

König also named this algorithm.[20] It relies on a prediction of the retarding capability of the retarder. Based on this predicition, the time of retarder actuation is computed which will result in the car leaving the retarder with the desired exit velocity and the retarder being actuated at the last possible moment.

C. Retardation with Constant Deceleration, Wong

In this algorithm, unlike the two above, the retarder is commanded to open and to close more than once (typically several times) for each car. This is done to approximate the case of constant deceleration through the retarder.[21] Due to the relatively slow response time of conventional retarders, the constant-deceleration velocity curve cannot be achieved exactly. The algorithm also contains a special feature to account for the slow response time and achieve accurate exit speed despite departure from the ideal constant-deceleration velocity curve.

D. Retardation with Constant Deceleration, Berti

This algorithm[22] is similar to the one above in that the goal is to obtain constant deceleration along the length of the retarder. In this algorithm, it is assumed that there is a means for continuous control of the retardation force exerted by the retarder. The retarder is commanded to exert that retardation force which will result in the desired exit speed with constant deceleration through the retarder.

VI Rollability Prediction Algorithms

A. Single Test Section

This algorithm has as input the velocity of each car at the entrance and at the exit of a section of track called the test section. Normally, the test section would be part of the track between the hump and the retarder being controlled. Rolling resistance is calculated using an energy equation such as the one given in part IV-A above. (In this case, V_X and V_C would be the entrance and exit speeds from the test section.)

$$R = (V_X^2 - V_C^2 + 2g\Delta h)\ \frac{m}{2S}$$

B. Multiple Test Section, Linear Regression

In this algorithm,[23] rollability is measured on two or more test sections between the hump and the retarder being controlled. In each case, the rollability is determined as described in A above. If the several rollabilities determined for a given car are denoted by $R_1, R_2, R_3, \cdots$, then the predicted rollability, R_p, is given by :

$$R_P = a_1R_1 + a_2R_2 + a_3R_3 + \cdots$$

where $a_1, a_2, a_3, \cdots$ are regression coefficients. These regression coefficients would be determined separately for each yard after testing with a statistically-significant number of cars (like 100).

C. Single Test Section Velocity-Dependent Linear Regression

This algorithm is discussed in the WABCO patent[24] in conjunction with the retarder control algorithm discussed in IV-B above. The algorithm is based on the assumption that rolling resistance varies linearly with velocity. Inputs to the algorithm include velocities at the entrance and exit of a single test section as in VI-A above. First the factor, K_U is defined

$$K_U \equiv \frac{2}{V_1 + V_2}\left[G_r - \frac{66.9}{S}\left(V_1^2 - V_2^2\right)\right] \quad ,$$

where:

V_1 = Velocity at the entrance to the test section

V_2 = Velocity at the exit of the test section

S = Length of the test section

G_r = Average grade of the test section

Next, the factor, K_D, which is akin to the rolling resistance, is computed:

$$K_D = A_T K_U + B_T \quad .$$

The constants A_T and B_T are obtained (presumably) by regression analysis from test data for a statistically-significant number of cars. Different values of A_T and B_T are used for each weight class. Presumably, A_T is approximately equal to the average exit velocity from the tangent point retarder for that weight class.

Footnotes:

1. König, Helmut, Control algorithms for rail retarders and closing-up devices in marshalling yards, Monthly Bulletin of the International Railway Congress Association, Vol. V, No. 12, December 1969.
2. Berti, Roland J., Automatic control means for retarders, U.S. Patent 3,283,146, November 1, 1966.
3. Budway, R.J., and McGlumphy, G.F., Retarder control systems for automatic railroad classification yards, U.S. Patent 3,946,973, March 30, 1976.
4. Wong, P.J., and Ratner, R.S., Hump yard retarder control system, U.S. Patent 3,745,334, July 10, 1973.
5. Wong, P.J., Ross, D.W., and Gardiner, K.W., Rollability predicition system, U.S Patent 3,689,788, September 5, 1972.
6. König, op. cit., pages 501-502.
7. König, op. cit., pages 502-503.
8. Budway and McGlumphy, op. cit.
9. Budway and McGlumphy, op. cit., Equation 1.
10. Budway and McGlumphy, op. cit., Figure 3.
11. Auer, J. H. and Kendall, H. C., Automatic car retarder control system, U.S. Patent 3,268,725, August 23, 1966.
12. Berti, op. cit., Equation 1.
13. König, op. cit., page 498.
14. Budway and McGlumphy, op. cit., Equation 2a.
15. Wong et al, op. cit., Equation 4.
16. Budway et al, op. cit., Equation 4.
17. König, op. cit., page 508.
18. Berti, op. cit.
19. Budway and McGlumphy, op. cit.
20. König, op. cit., page 509.
21. Wong and Ratner, op. cit.
22. Berti, op. cit.
23. Wong, Ross, and Gardiner, op. cit.
24. Budway et al, op. cit., Equations 4a and 4b.