MODELLING OF LOCOMOTIVE NORMAL LOAD

ABSTRACT

The paper deals with two topics. The one is strictly railways, that is theoretical theses for calculation of locomotive load at respective gradient. The second is an overview of computer program MS Access with the basic terms and definitions included in the program itself. It is intended to bring closer the language of information technology to the railways. The developed program for calculating the allowed mass of trains that can be hauled by certain locomotives enables fast calculation of any of the traction variants. A limitation related to mass has been included in the program.

KEYWORDS

timetable, calculation of train traction, performance characteristic, specific normal load

1. INTRODUCTION

Train timetable is the executive plan of train traffic organised for the transport of passengers and goods and for the railway purposes. Timetable co-ordinates the transportation requirements with available material-technical and personnel resources. The available material-technical resources as the basic elements for making a timetable include:
- condition of lines and railway station tracks,  
- condition of safety-signalling, telecommunication devices and machinery and information system,  
- condition of stable electric traction facilities,  
- condition of passenger and freight wagon stock  
- condition of traction vehicles.

For train scheduling the following parameters are also necessary: time necessary to run a certain section and the planned speed limitations.

These data may be obtained by good calculation of traction. Apart from obtaining the basic values to schedule the trains, thoughtful calculation of traction allows calculation of a whole series of values significant for the traction analysis from several aspects.

Modelling of the locomotive normal load is part of the whole calculation of the train traction. However, attention has to be paid to performance characteristic as essential element of these calculations.

If traction calculation is used from several aspects, it becomes complex and comprehensive, resulting in even more demanding performance. In order to solve this problem, computers need to be used and software developed based on extensive analyses in mathematical and logical sense, as well as good knowledge of adequate programming language.

2. DETERMINING OF SINGLE VALUES

In order to determine the train mass that a locomotive can haul at a steady speed, the tractive force needs to be defined. Here, train traction is considered in the least favourable case, which means at a relevant gradient. In such case the tractive force equals:

$$F = \frac{1}{100} \times \left[ m_l \times (w_{hl} + i_m) + m_v \times (w_{hv} + i_m) \right]$$

where:
- $F$ [kN] – tractive force,  
- $m_l$ [t] – locomotive mass,  
- $W_{hl}$ [daN/t] – specific normal resistance for the locomotive,  
- $i_m$ [%] – relevant gradient,  
- $m_v$ [t] – train mass,  
- $w_{hv}$ [daN/t] – specific normal resistance for the train.

From this equation the mass of the train that can be hauled on the relevant gradient at a constant speed is calculated

$$m_v = \frac{100 \times F - m_l \times (w_{hl} + i_m)}{w_{hv} + i_m} \quad [t]$$

or

$$m_v = \frac{100 \times (F - W_{hl}) - m_l \times i_m}{w_{hv} + i_m} \quad [t]$$

$W_{hl}$ [kN] – normal resistance for the locomotive.

Tractive force is determined from the performance characteristics for every locomotive separately. The performance characteristics most often consist of three curves:
- curve a – usually denotes the greatest tractive force a locomotive can realise regarding the adhesion force,
M. Nikšić, D. Kaužljar, D. Magličić: Modelling of Locomotive Normal Load

1. electric locomotives,
   - alternate current – series 1141 and 1161,
   - direct current – series 1061, and
   - alternate Thyristor current - of series 1142,
2. diesel-electric locomotives – series 2061, 2062, 2063, 2041, 2042, 2043 and 2044,
3. diesel- hydraulic locomotives - series 2131, 2132, 2133 and 2141.

B. Functions of locomotive tractive force

Based on the performance characteristic of single locomotives in the following table there is an overview of examples of defined tractive forces functions according to the locomotive 1141 series. The functions of tractive forces are suitable for any calculation which includes the tractive force. Such a case occurs in the computer program that calculates locomotive load.

For locomotives of series: 1141, 1142, 1161, 1061
- tractive force [kN] A – denotes constant regime,
- tractive force [kN] B – denotes one-hour regime.

For locomotives of series: 2062, 2063, 2044, 2043 the tractive force is calculated with:
- electrical heating turned off,
- electrical heating turned on.

For locomotives of series: 2141 tractive force is calculated for:
- passenger transfer,
- cargo transfer.

For locomotives of series: 2131, 2132, 2133 tractive force is calculated for:
- first degree of transfer,
- second degree of transfer.

C. Normal resistance function

Normal resistances for locomotives are also defined as functions based on the respective diagrams, and in Table 2 there is an example of normal resistance for the locomotive number 1141.

Table 1: Example of tractive force of the locomotive number 1141

<table>
<thead>
<tr>
<th>Speed range [km/h]</th>
<th>Tractive force F [kN]</th>
<th>Speed range [km/h]</th>
<th>Tractive force F [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Locomotive 1141 (up to 120 km/h)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 ... 37</td>
<td>F = 176</td>
<td>0 ... 21</td>
<td>F = 189</td>
</tr>
<tr>
<td>38 ... 82</td>
<td>F = 221*(8 + 0,1<em>V) / (8 + 0,18</em>V)</td>
<td>22 ... 86</td>
<td>F = 221*(8 + 0,1<em>V) / (8 + 0,18</em>V)</td>
</tr>
<tr>
<td>83 ... 94</td>
<td>F = -1,675*V + 294,65</td>
<td>87 ... 91</td>
<td>F = -1,46*V + 280,86</td>
</tr>
<tr>
<td>95 ... 120</td>
<td>F = 481105/V * 2 - 84,4*V + 2597</td>
<td>92 ... 120</td>
<td>F = 481105/V * 2 - 84,4*V + 2597</td>
</tr>
<tr>
<td>Locomotive 1141 (up to 140 km/h)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 ... 94</td>
<td>F = 148</td>
<td>0 ... 76</td>
<td>F = 159</td>
</tr>
<tr>
<td>95 ... 121</td>
<td>F = -1,18*V + 259,4</td>
<td>77 ... 96</td>
<td>F = 221*(8 + 0,1<em>V) / (8 + 0,18</em>V)</td>
</tr>
<tr>
<td>122 ... 140</td>
<td>F = 931826/V * 2 - 35,22*V - 2408,7</td>
<td>97 ... 119</td>
<td>F = -1,35*V + 283,5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>120 ... 140</td>
<td>F = 931826/V * 2 - 35,22*V - 2408,7</td>
</tr>
</tbody>
</table>

Table 2: Example of normal resistance for the locomotive number 1141

<table>
<thead>
<tr>
<th>Types of locomotives</th>
<th>Normal resistances for locomotives $W_{nn}$ [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1141</td>
<td>$1.64 + 0.0328(V/10)^2$</td>
</tr>
</tbody>
</table>

D. Specific normal resistance for single types and compositions of trains

Specific normal resistance for a train depends on the type and composition of the train and it is calculated according to the following calculations:

- mixed cargo trains:
  $$W_{nn} = 1.5 + 0.0625 \left(\frac{V}{10}\right)^2$$

- heavy cargo trains:
  $$W_{nn} = 1.5 + 0.0238 \left(\frac{V}{10}\right)^2$$

- passenger trains composed of two-axle coaches:
  $$W_{nn} = 1.5 + 0.040 \left(\frac{V}{10}\right)^2$$

- passenger trains composed of four-axle coaches:
  $$W_{nn} = 1.5 + 0.0222 \left(\frac{V}{10}\right)^2$$

- passenger trains composed of high-comfort four-axle coaches:
  $$W_{nn} = 1.5 + 0.0159 \left(\frac{V}{10}\right)^2$$

3. THE CONCEPT OF MS ACCESS PROGRAM

The calculation of locomotive load for different types and compositions of trains is solved by calculating complex values. As the best solution, a computer program for calculating these has been developed. This program carries out the following steps:

- operation regime – it can be constant or one-hour,
- electrical heating – it can be turned on or off,
- transfer type – it can be passenger and cargo,
- transfer rate – it can be first and second,
- highest travelling speed – it can be for the locomotive 1141 (120 or 140 km/h) and for the locomotive 1142 (120 or 160 km/h),
- type of traffic – it can be passenger and cargo
- type of traffic subgroup – it can be in passenger (trains of two-axle coaches, four-axle trains and

Table 3: Overview of actions within the program

<table>
<thead>
<tr>
<th>Steps</th>
<th>Number of the locomotive</th>
<th>Program action</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st step</td>
<td>all locomotives</td>
<td>Selection of locomotive number</td>
</tr>
<tr>
<td>2nd step</td>
<td>a) for el. locomotive:</td>
<td>Selection of operation regime</td>
</tr>
<tr>
<td></td>
<td>b) for locomotive no: 2062, 2063, 2043, 2044</td>
<td>Selection of el. heating condition</td>
</tr>
<tr>
<td></td>
<td>c) for locomotive no.: 2141</td>
<td>Selection of transmission type</td>
</tr>
<tr>
<td></td>
<td>d) for locomotive no.: 2131, 2132, 2133</td>
<td>Selection of transmission rate</td>
</tr>
<tr>
<td>2nd a step</td>
<td>for locomotive no.: 1141, 1142</td>
<td>Selection of highest travelling speed</td>
</tr>
<tr>
<td>3rd step</td>
<td>all locomotives</td>
<td>Selection of traffic type</td>
</tr>
<tr>
<td>4th step</td>
<td>all locomotives</td>
<td>Selection of traffic subgroup</td>
</tr>
<tr>
<td>5th step</td>
<td>all locomotives</td>
<td>Performing calculation</td>
</tr>
<tr>
<td>6th step</td>
<td>all locomotives</td>
<td>Printing calculation</td>
</tr>
<tr>
<td>7th step</td>
<td>all locomotives</td>
<td>quitting the program</td>
</tr>
</tbody>
</table>

Printing format of the locomotive load calculation results

Locomotive 1142
Constant regime
Passenger train – four-axle coaches

Table 4: Example of load calculation for the locomotive of the 1142 series

| Gradi- | 40  | 50  | 60  | 70  | 80  | 90  | 100 | 110 | 120 | 130 | 140 | 150 | 160 |
|dent / |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Km    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 0     | 3000| 3000| 3000| 3000| 3000| 3000| 3000| 2789| 2249| 1833| 1508| 1250| 1044|
| 1     | 3000| 3000| 3000| 3000| 3000| 3000| 2743| 2236| 1840| 1527| 1276| 1083| 906 |
| 2     | 3000| 3000| 3000| 3000| 3000| 2747| 2249| 1861| 1553| 1305| 1103| 956 | 798 |
| 3     | 3000| 3000| 3000| 2904| 2733| 2298| 1902| 1591| 1341| 1137| 969 | 855 | 712 |
| 4     | 2776| 2680| 2570| 2451| 2326| 1972| 1645| 1386| 1177| 1005| 862 | 744 | 641 |
| 5     | 2359| 2288| 2207| 2117| 2022| 1724| 1447| 1226| 1047| 899 | 775 | 706 | 582 |
| 6     | 2049| 1994| 1931| 1861| 1786| 1530| 1290| 1098| 942 | 812 | 703 | 650 | 531 |
| 7     | 1808| 1765| 1715| 1658| 1598| 1373| 1162| 992 | 854 | 739 | 642 | 602 | 488 |
| 8     | 1616| 1581| 1540| 1494| 1444| 1245| 1056| 904 | 780 | 677 | 590 | 560 | 451 |
| 9     | 1460| 1431| 1397| 1358| 1316| 1137| 966 | 830 | 717 | 624 | 544 | 524 | 418 |
| 10    | 1330| 1305| 1276| 1244| 1208| 1045| 890 | 765 | 663 | 577 | 505 | 492 | 389 |

4. CONCLUSION

Timetable is the operation process which encompasses all the elements needed to carry out the transportation such as material and technical resources and guidelines in passenger and cargo transport. In order to achieve the best possible scheduling of a timetable, the elements that are included in the timetable need to be of the highest quality as well. The elements required for the timetable include also calculations of the normal resistance of a locomotive.

The current organisation of the Hrvatske željeznice has been organised in such a way that within the Department for Traction of Trains and Train Vehicles, the train travelling times are calculated on the basis of the characteristics of tractive vehicles. Such a condition leads to certain errors in timetable due to the following reasons:

- the calculation of travelling times requires elements that are not related to the vehicle traction (track characteristics, planned train mass) so that a more accurate way would be to calculate the timetable at the Timetable Service,
- in calculating the travelling times, the characteristics of new tractive vehicles are used leading to differences between the calculation results and the actual travelling times in practice.

Modelling of the locomotive normal load is the introductory work in defining of all elements needed for scheduling, and directed towards the calculation and quality of performance characteristics that can be calculated by various methods. It has to be noted that the construction year of the tractive vehicle and the replacement of the traction vehicle components are the elements which can influence accurate performance characteristic of the tractive vehicle.

The development of the railway traffic in Europe has started many new relations as well, ways of dealing with problems and ways, the basic activity - of performing transport. One of the relations that will undergo changes is also the way and type of providing elements of the train traction for the development of timetables.

SAŽETAK

MODELIRANJE OPETREĆENJA LOKOMOTIVA U RAVNINI

Cjelokupni rad obrađuje dvije tematike. Prva je stroga željeznička i to teoretske postavke za proračunavanja optere-

**LITERATURE**

**Books**


**Manuals and Regulations**


[2] Pravilnik 221- Pravilnik vuče vlakova, Hrvatske željeznice, Zagreb, 1999

**Scientific Articles**


**from the Internet**