Data-Driven Estimation of the Permissible Running Speed of a Self-Propelled Railcar from Frame Strain-Gauge Measurements

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Abstract

Speed limits for special self-propelled rolling stock are usually set from design documents, while the actual stress state of an aged frame may differ. This thesis shows how a strength-based speed limit can be obtained directly from running-test data. Maximum stresses measured by 16 strain-gauge channels on the frame of an ADM-1 railcar at 10, 30, 55 and 60 km/h were fitted by linear regression. The models explain 79–99% of the variance (median $R^2 = 0.92$). The most loaded zone, under the diesel-engine beam, reaches the permissible stress of 152.75 MPa at about 54 km/h. The same regression structure can serve as a first surrogate model for machine-learning-based monitoring of electric rolling stock.

Keywords

self-propelled rolling stock, frame, strain-gauge measurement, regression, permissible speed, surrogate model, machine learning.

Introduction

More than 180 units of special self-propelled rolling stock operate on the railways of Uzbekistan, and about 64% of them have served over 20 years [1]. Life extension of these vehicles requires knowing the conditions under which the frame stays within its strength limits. Running speed is the operating parameter that the driver controls most directly, and frame stress grows with it [1, 2]. The aim of this work is to turn running-test measurements into a speed limit with a transparent, reproducible model.

Methods

Strain gauges of type BF350-10AA were installed at stress-concentration zones of the ADM-1 frame identified by a finite element model, following GOST 31846-2012 [3]. Tests were run on the Uzbekiston–Chinoz line section on straight track and curves of 600 and 900 m radius. Finite element and measured stresses agreed within 5–10% [1]. For every channel k, the maximum stress was fitted as a linear function of speed v, and the limit speed was found where the model reaches the permissible stress [σ]:

$$\sigma_k(v) = a_k + b_k \cdot v, \quad v_k^* = ([\sigma] - a_k) / b_k \qquad (1)$$

The permissible stress for the working, traction and design-speed modes is [σ] = 152.75 MPa [1, 3]. The coefficient of determination R^2 was used to judge whether a linear model is adequate.

Results

Table 1 lists the fitted models. Zones I–IV are lightly loaded, with stress gradients below 1 MPa per km/h and limit speeds far above the operating range. Zones VI and VII carry the highest loads. In zone VII the limit is reached at 54–56 km/h, which agrees with the exceedance of normative stresses observed at 50–60 km/h in the running tests [1].

Table 1. Linear stress–speed models of the ADM-1 frame channels

Channel	Zone	a, MPa	b, MPa per km/h	R^2	v*, km/h
1	I	-0.48	0.279	0.85	548
2	II	-2.69	0.746	0.94	209
3	II	-4.98	0.928	0.93	170
4	II	0.22	0.751	0.93	203
5	II	-2.83	0.759	0.83	205

Channel	Zone	a, MPa	b, MPa per km/h	R^2	v*, km/h
6	III	-3.06	0.915	0.88	170
7	III	-6.14	0.978	0.92	162
8	III	-4.26	0.847	0.93	185
9	IV	-0.50	0.880	0.90	174
10	V	-1.88	1.227	0.79	126
11	V	-0.75	1.065	0.88	144
12	VI	28.10	1.508	0.91	83
13	VI	13.29	1.665	0.98	84
14	VI	18.04	2.011	0.99	67
15	VII	-1.95	2.757	0.96	56
16	VII	5.51	2.729	0.92	54

Linear interpolation between measured points gives 54.8 km/h for channel 16, close to the regression value of 53.9 km/h. The regression is therefore slightly conservative, which is the safer direction for a speed limit.

Conclusions

A strength-based permissible speed of about 54 km/h was derived for the ADM-1 frame directly from strain-gauge data. Simple linear models describe the stress–speed relation well, so they can serve as transparent baselines. In future work, the same structure will be extended to machine-learning surrogates such as gradient-boosted trees [4], trained on on-board data of electric locomotives, to support condition-based maintenance and fatigue-aware speed advice.

References

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