Fatigue life analysis of railway couplers using rainflow: A comparison between locotrol and tricotrol configurations

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Introduction

Couplers in heavy-haul trains endure millions of load cycles due to traction, braking and track conditions, leading to fatigue cracks and failures. Distributed power systems help control these forces, and Tricotrol, a configuration combining head-end, mid-train and tail-end locomotives, enhances this by distributing tractive and braking forces more evenly. This balanced layout reduces longitudinal load peaks and stress reversals along the train.This study analyzes the impact of Tricotrol on coupler fatigue life in a 135-cars train with 17,200 tonnes gross weight. Stress cycles and damage were quantified using the Rainflow method applied to dynamic simulation data, validated by instrumented cars. Results show that Tricotrol significantly smooths force transitions, lowers the number of damaging stress cycles, and extends coupler fatigue life compared to traditional distributed power configurations.

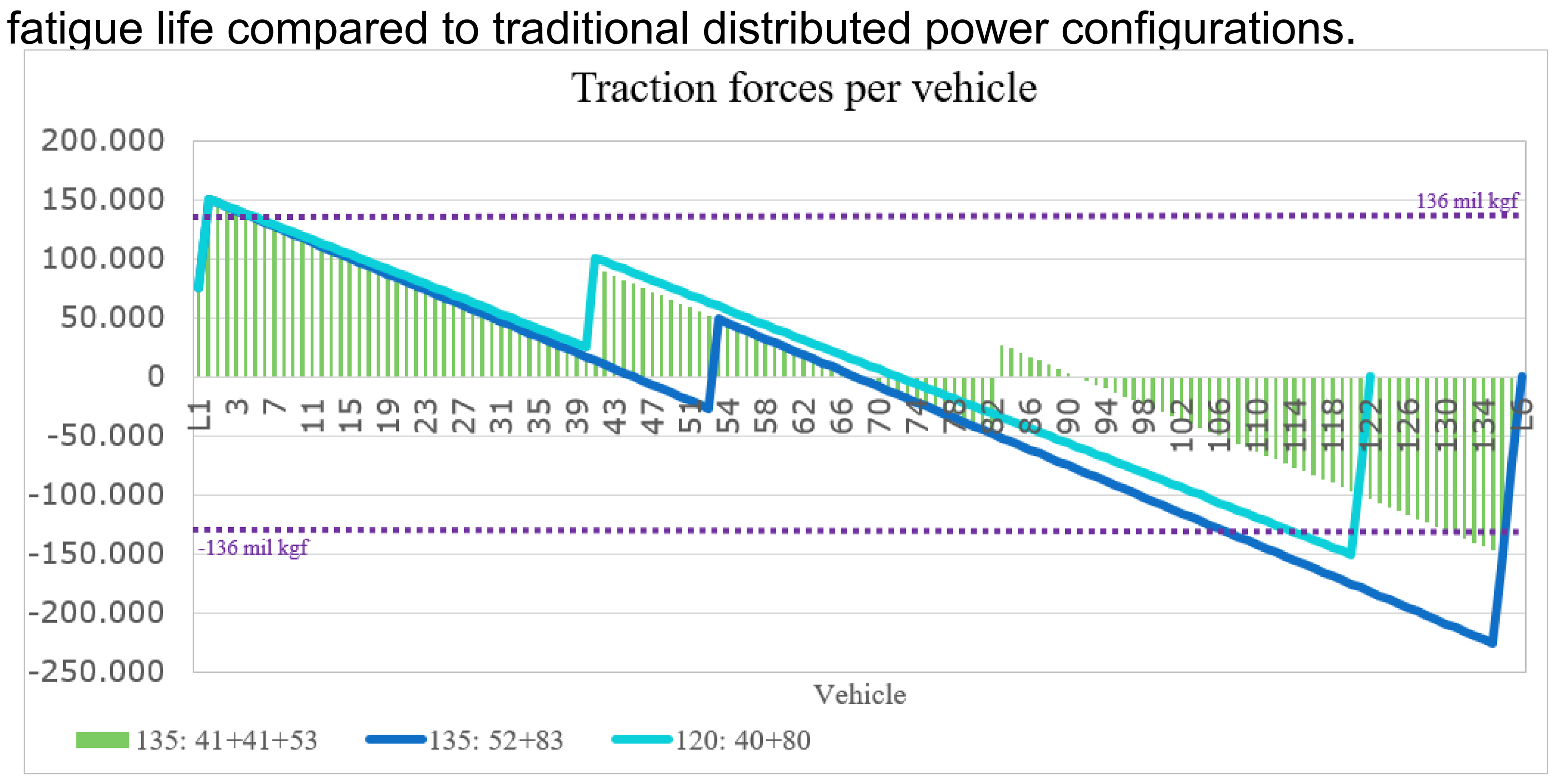

Figure 1: Longitudinal force profile along the 135-cars consist under Tricotrol configuration.

Experimental work

A comprehensive simulation campaign was conducted using the FTS longitudinal train dynamics model calibrated with real force data from two instrumented cars (HPT and HTT) installed in representative train positions. The simulation replicated actual gradients, curves, operational speeds and typical slack action events encountered along the Rumo network's most challenging segments. Forces recorded at each coupler location were processed using the Rainflow method to decompose complex time series into discrete stress cycles, identifying their amplitude and mean stress for fatigue assessment. Material fatigue properties for ASTM A242 structural steel, commonly used in coupler castings, were adopted, together with a fatigue notch factor of 1.12 to conservatively account for geometric stress concentrators and wear. Cumulative damage calculations considered the full spectrum of cycle ranges. Key metrics such as total number of cycles to failure (NT), equivalent life in miles (Lc), and estimated operational years were computed under standard annual mileage assumptions. Sensitivity analyses were also performed to evaluate how variations in train loading, driving style and distributed power placement could affect force profiles and resulting fatigue life.

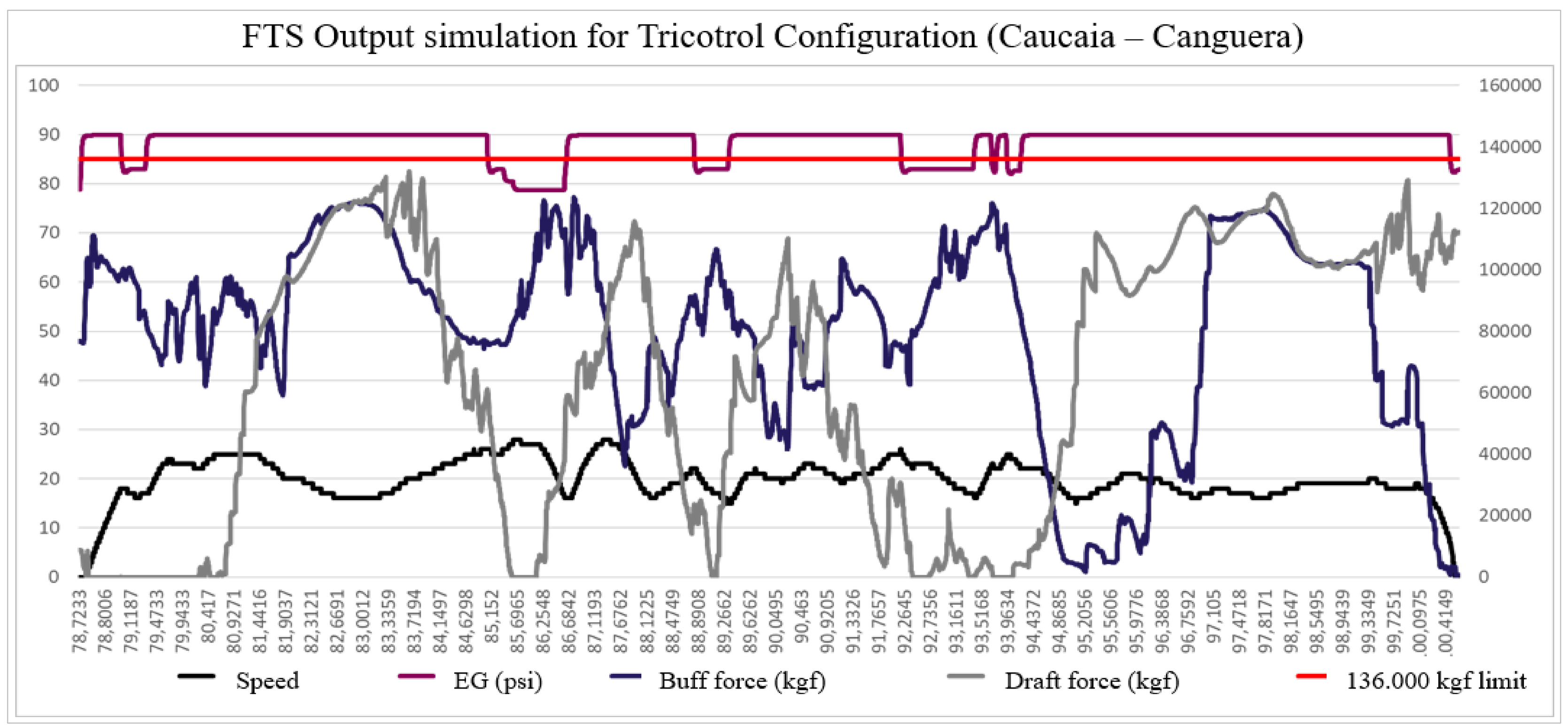

Figure 2: Snapshot of FTS simulation section used to assess Tricotrol fatigue life between Caucaia and Canguera.

Results

Results show that the Tricotrol configuration significantly improves the fatigue resilience of couplers by smoothing out both traction (draft) and compression (buff) force peaks along the train length. The Rainflow histogram reveals a notable shift towards lower-amplitude stress cycles compared to conventional Locotrol distributed power. Specifically, the total number of cycles to failure (NT) was calculated at approximately 15.6 million cycles, translating to an equivalent running distance (Lc) of about 4.6 million miles. Considering average annual mileage typical for this service, this extends the coupler's operational life to an estimated 47.8 years. This represents an increase of more than 100% compared to legacy configurations without optimized distributed power placement. Furthermore, the cycle distribution shows fewer occurrences of high-amplitude compressive loads, which are particularly damaging in fatigue propagation. These improvements validate the advantage of placing remote locomotives strategically to better balance in-train forces. The consistent force profile reduces abrupt changes and slack run-ins, minimizing stress reversals that accelerate crack growth. Together, these results demonstrate the robustness of Tricotrol as a solution to prolong coupler life and reduce lifecycle costs.

Min (tf)	Max (tf)	Amplitude (tf)	Cycles	% Total
-123	101	112	6	0.044
-20	100	60	2	0.015
-17	51	34	45	0.330
-80	-66	7	3078	22.596
-104	-50	27	565	4.148
-60	23	41	436	3.201
-11	57	34	20	0.147
-50	72	61	8	0.059
-60	19	39	144	1.057
-35	12	23	328	2.408
-110	123	116	6	0.044
-109	60	84	5	0.037
-101	-10	45	762	5.594
-18	20	19	811	5.954
-43	27	35	457	3.355
-30	22	26	78	0.573
-70	65	67	9	0.066
-10	50	30	68	0.499
-9	43	26	1053	7.730
-31	85	58	28	0.206
-43	55	49	966	7.091
-121	145	133	3	0.022
-3	93	48	78	0.573
-3	77	40	100	0.734
-68	-2	33	378	2.775
-40	16	28	4139	30.385
-107	22	64	9	0.066
-110	11	60	10	0.073
-120	130	125	1	0.007
-10	140	75	29	0.213
	Total		13622	100.000

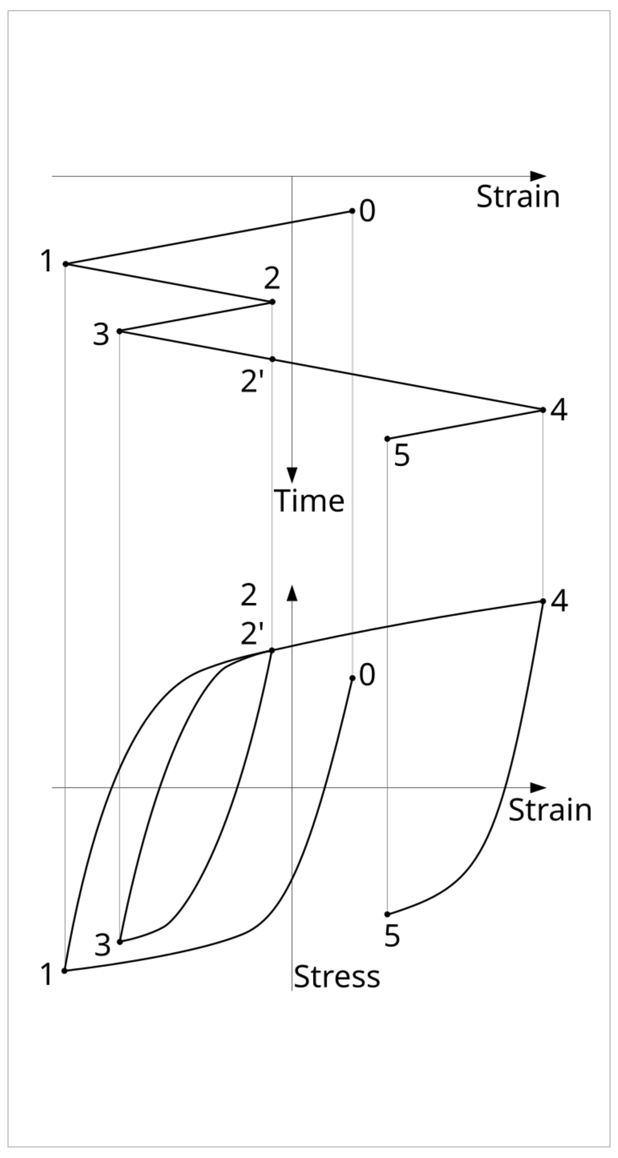

Figure 3: Estimated fatigue life based on cumulative damage analysis.

Conclusions

Implementing Tricotrol in a 135-wagon heavy-haul train notably enhances coupler fatigue life by minimizing harmful force cycles. The projected life extension to nearly 48 years supports cost-effective fleet management, reduces maintenance interventions, and reinforces safe operations. These findings advocate for broader use of multi-point distributed power configurations and highlight Rainflow analysis as a robust tool for fatigue life assessment in railway applications. Future studies will expand this method with real-time monitoring and machine learning integration for proactive asset management.

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