Guiding steam locomotives along sometimes winding roads

Or how to reduce the conflict between straight track and curve riding, with notes on its actual relevance

Hendrik Kaptein, for ASTT conference, Derby, 6 October, 2024

1. The problem: bended rails at times

- Another balancing act: last time on reciprocating steam engine locomotive balancing & "solutions" of the problem in longer "fixed" wheelbases: remember? (no worries)
- But then long fixed wheelbases don't easily fit into curves (Soviet 4-14-4, see overleaf)
- Radical solutions: no curves (NL rail authorities trying to do away with switches → less curvature but probably unrelated to steam locomotive accommodation)
- *La mort du rail*? Or at least an end to steam traction & its manifold of other problems? (Put all remaining heritage steam on static display → no more problems …)
- Not that practical → long & winding road ahead …


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1. The problem: bended rails at times

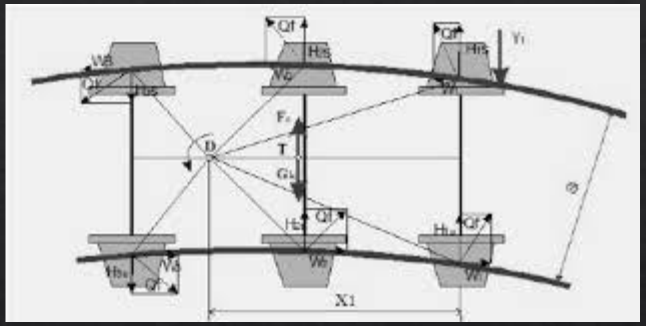
- So **how to optimally design conventional rigid frame steam locomotive wheel arrangements in order to ensure both good straight track riding and adequate curve negotiation**?
- Something may still be done concerning track curvature itself: parabolic curve connections, track widening (not practiced in the UK?), sensible limits to yard, siding &c. curve radii (probably rather impractical as rigid rame steam / other loco's are marginal phenomena anyway)

1. The problem

- Main issues of the straight track / curve problem (simplified!):

a. *Straight track stability → relatively long fixed or at least (spring / roller / damping &c. controlled) wheelbase.* But this is at odds with

b. *Short wheelbase → at least some wheel-rail parallellism in curves*



- "More a than b": more wheel + flange / rail friction in curves, → higher track resistance, less adhesion (e.g. HSB experience), potential derailment in (tight) curves, …

- "More b than a": insufficient straight track (+ wide curve) stability at speed

1. The problem

Totally simplified summary of relevant rail vehicle curve forces:

a. Static: “squeezing” a straight rigid wheelbase into curved track (partly accomodated by lateral play + complications due to restoring forces by springs or otherwise)

b. Dynamic: acceleration of revolving motion around vertical axis caused by transition from straight to curved track (mitigated by parabolic curve connections)

c. Dynamic: rather smaller forces on front end behind continuous rotation during constant curve negotiation

d. Dynamic v.: centrifugal forces caused by curve negotiation

All causing adverse (+ non-parallel) flange loading → wheel & track wear, …, derailment

Overview

(1. Intro)

2. Ideal & less ideal solutions: from Talgo to Garratt &c. & back to single frame steam locomotives

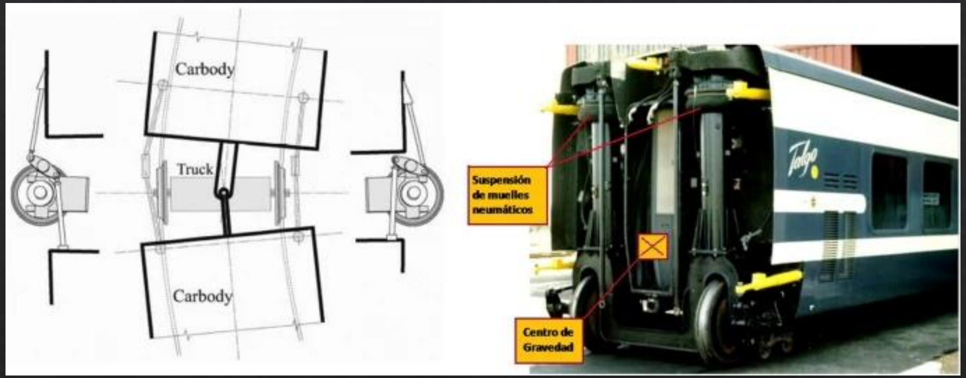
3. Radial curve adaptation mechanisms for (driving &) coupled axles in rigid frames

4. Orthodox solutions, Gölsdorf's wrongly forgotten heterodoxy

5. Agenda, including suggestions for *Clan* & other reconstruction / new projects

2. Ideal wheel-rail interaction & approaches

- The best solution is almost a 100 years old: TALGO: uncoupled wheels on a common axle between adjoining vehicles, steered by Watt-linkage connected to these two vehicles



- → well-nigh perfect wheel-rail parallellism both on straight track and in (high speed & tight low speed) curves (absence of self-steering due to uncoupled wheels no problem at all)
- Not that practical for conventional steam locomotives …

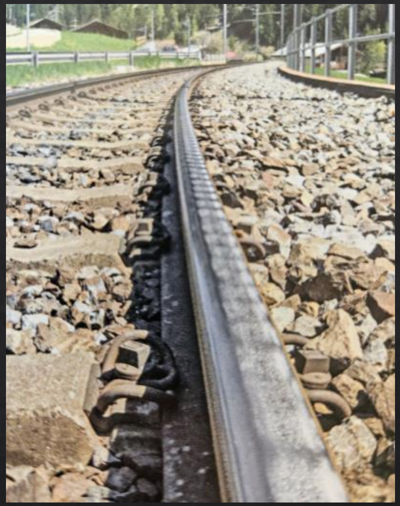
2. Ideal wheel-rail interaction & approaches

- Less radical: e.g. SBB Re 460: four wheeled bogie with (complex) axle steering, six wheeled bogies with simple end axle location enabling radial adjustment in curves, e.g. Voith Maxima &c., …
- Or normal bogies, under steam locomotives as well: Heilmann steam-electric, later turbo-electrics (still on some drawing boards), but also Heisler, Shay, …
- Still more conventional & widely applied to steam locomotives: Mallet / articulated, Garratt & modified Garratt, … leading back to the fixed wheelbase “single frame” issue

2. Ideal rail-wheel interaction & approaches

Modern (bogie) solutions superior concerning wheel / track conflicts in curves?

- E.g. persistent problems with (flexicoil) bogie riding even in wide curves at moderate speeds: rapid wheel wear, rail & track damage, …



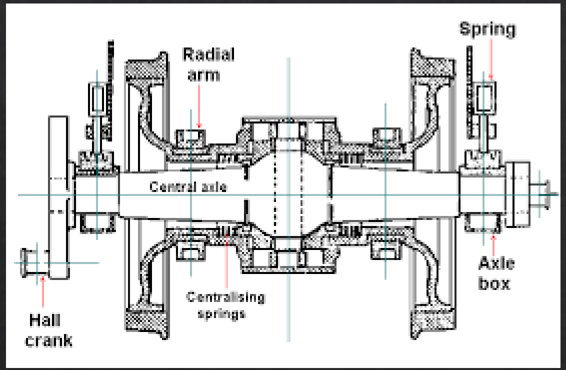
- Combino wheelsets still worse (more or less fixed to vehicle bodies)

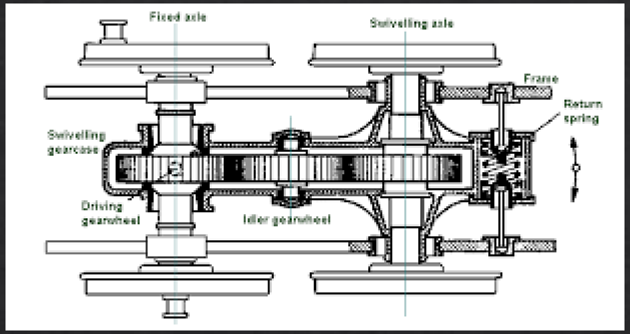
"Listen for yourself" … (*nb*: wheel-rail interaction very much more complex than suggested here …)

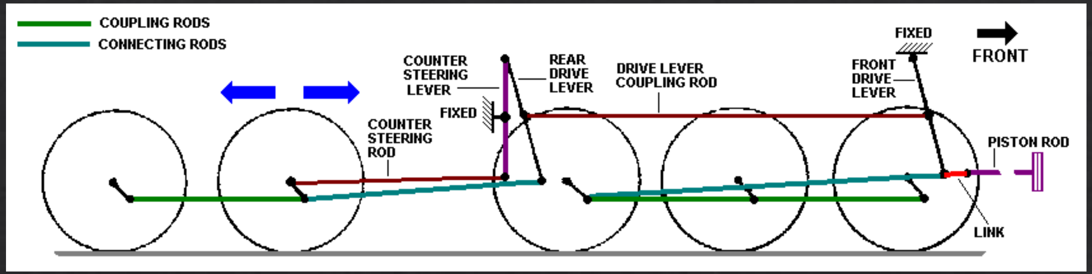
3. Rigid frame, freely moving wheels

- Simplest solution: 2-2-2: single driving axle with thinner wheel flanges, leading & trailing "Novotny" style carrying axles: // self-steering six wheel bogie in optimal wheel-rail parallellism: no "angle of attack". But this implies rather light train loads (or impracticable axle loads)
- Carrying axles / idler wheels not the problem: radial Adams, Cartazzi, Bissel, Busse, Krauss-Helmholtz, Zara, … + bogies of course, both leading & trailing, + trailing four wheel trucks &c.: all both accommodating lateral play & more or less minimising "angles of attack"
- Why not try coupled wheelset radial play for curve adaptation? Engerth, Klien-Lindner, Luttermöller, Hagans, …

3. Rigid frame, “free” wheels







Klien-Lindner, Luttermöller, Hagans

- Common problem: mechanical complexity → (extra weight,) wear → play → malfunctioning
- Rather numerous for some time (around 1900 in Germany & elsewhere) but given up soon after for good reasons & not of much future interest (won’t fit “parental rights” / type approval anyway)

4. Conventional solutions

- Standard solution: **compromise** between relatively **short fixed wheelbase** (for straight track stability) so as to accomodate sufficient **"outer end" lateral play** (radial – in uncoupled leading & trailing axles) for curve negotiation
- Continent / US: fixed wheelbase extending over no more than driving axle (sometimes with thinner flanges) + adjacent coupled axles,
- + "outer end" restoring forces, by springs, rockers, rollers (better), sometimes on leading coupled wheelsets as well (e.g. Stateside Northerns)

4. Conventional solutions

- E.g. standard Pacific: leading bogie with spring controlled lateral play, idem radial trailing axle, fixed wheelbase = driving + coupled axles
- Or typical continental 2-10-0: leading Krauss-Helmholtz (like) truck coupling “radial” leading axle with leading coupled axle emulating a “real” bogie, fixed wheelbase = second, third & fourth driving & coupled axles, trailing coupled axle with ± “free” lateral play
- &c.

→ Uneasy compromise: with 2 cyls not much stability at speed on any track straight or curved, occasional derailment in tight curves

4. Conventional solutions

- Anecdotical but still: German standard Pacific *Reihe* (series) 01 (from 1925): leading bogie not that close to leading coupled wheelset, linear lateral spring control → center force too small given the need to avoid excessive restoring force at extreme deflections (→ risks of derailment in tight curves). Result: leading bogie was soon found to contribute nothing to lateral stabilisation at speed, one factor still further worsening the riding qualities of these (insufficienty balanced) 2 (outside) cyl express loco's (not unique in this respect)
- N&W J 4-8-4: Lesson learnt (though not necessarily from ze Germans): stiff lateral bogie + trailing truck lateral control in order to reduce (2 cyl) sway → occasional slow speed derailments in shunting yards / other tight curves

4. Conventional solutions

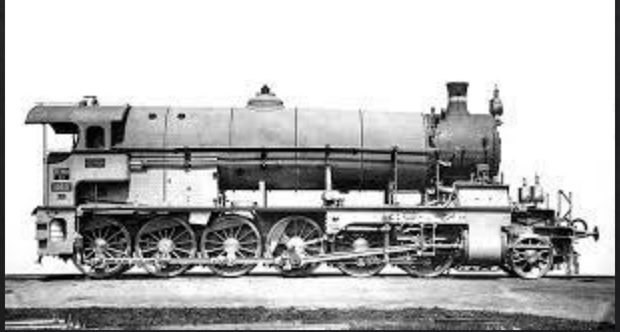
- Cf. the Indian Pacific 1937 tragedy as discussed before: wrongly designed leading bogie, given relatively short fixed wheelbase &c. (the German 01 effect at large, // Peppercorn's scary Pacifics &c.)

4. Conventional solutions

- Lower speeds (not that practical but sometimes simply imposed by adverse / deadly experience), more cylinders (less sway, more expensive), …
- More advanced semi-solutions: Beugniot (± in *Revolution* as well), Schwarzkopf-Eckhardt, … all at the price of added weight, complexity & attendant extra first / maintenance costs
- Still this unhappy compromise of "short central fixed wheelbase + flexible extremities" generally lived with all over the world
- Backed by highly complex but impractical "applied mathematics" "fitting" wheelsets into curves: "fixed centre" the wrong principle

4. (Un)conventional solutions

- Here comes (or better came) **Karl Gölsdorf** (already well-known one may presume, comparable as he is to Stephenson & Chapelon): though constrained by axle loads no higher than about 15 t (& by inferior coal) he designed & built steam loco's with exceptional power / weight ratios for his time
- One of his many masterpieces: kkStB 2-12-0 4 cyl compound mountain express locomotive series 100 (1911, as already discussed last year):



4. (Un)conventional solutions

- Two main differences (compared to “the rest of the world”):

a. *Central lateral axle play* (instead of at the extremes)

b. *No restoring forces against lateral / radial play*

a. → (Much) longer fixed wheelbase, good for lateral stability (no difference for wheel / rail parallelism)

b. → No harmful static lateral forces on the track

4. (Un)conventional solutions

- No unwanted / harmful static wheelrim-rail forces: e.g. laterally spring loaded leading Bissel unloads leading coupled axle in (wide) curves. OK but tight (yard &c.) curves force the Bissel (or bogie) further out, increasing the restoring force & thus increasing (wear &) derailment risks (like with the N&W J's indeed)
- "Symmetric" spring &c. loaded leading & trailing Bissels / bogies → no unloading effect on leading coupled axle (!) ← trailing axle restoring force "neutralises" leading axle restoring force. (E.g. trailing axle centring force in a right curve "pulls" the locomotive to the left …)

(Un)conventional solutions

- This is why Gölsdorf did away with restoring forces, replacing them with lateral *damping* (by no more than friction between axleboxes & frames): no static forces left, so no issues in tight curves, dynamic lateral damping providing (more than) adequate stability at speed, still further "lenghtening" the fixed wheelbase (good thing on straight track indeed).

→ Lengthening wheelbase → centre of loco gravity moves "inwards" relative to curves (good thing)

→ ± stress free curve riding as well, minimal flange / wheel & thus minimal permanent way wear as well (!)

(Not so) conventional solutions

- Next e.g. 2-6-4 express pasenger locomotive series 210 / 310 (1908 / 1911): virtual fixed wheelbase: leading Krauss-Helmholtz truck connecting leading Bissel wheelset with first coupled axle by centrally pivoted beam, thus coupling lateral movements like in a "real" bogie (*fixed* pivot, unlike not very successful German practice with spring controlled lateral pivot movement) … No rotational restoring forces or even damping here, + *idem* on trailing four wheel bogie (big grate ← bad coal)

(Bigger wheels → higher derailment risks with nonparallel wheels relative to the track:? But see e.g. Stroudley's successful express passenger engines with 6 ft. 6 in. leading coupled wheels w/o leading carrying axle / bogie)

(Un)conventional solutions

- Not completely original: e.g. 19th century American 4-4-0's, Prussian S3 4-4-0's (late 19th century), Moscow-Kazan Ry. 4-6-0's (around 1920), all with fixed bogie pivots, all relatively short loco's with "long virtual wheelbase" (still generally nothing much was done with Gölsdorf's ideas later on)
- Related unconventional solution: Chapelon's P.-O. 240.700 / 240A / 240 P (superpower 4-8-0 4 cyl compound, ± 100 t, 4,000 ihp, 39 ihp/t): no fixed wheelbase at all, virtual wheelbase consisting of laterally spring controlled leading four wheel bogie, followed by driving / coupled axles with lateral play / thinner flanges + only trailing coupled axle fixed laterally: reputedly superbly riding as wel

4. (Un)conventional solutions

- Back to last year: “Gölsdorf style” long wheelbase setups *effective against* (2 & 3 cyl) *sway* as well → reciprocal balancing may be reduced to countering surge only (like in BR 9F 2 cyl 2-10-0: fixed wheelbase extending over all driving & coupled wheels, “Spaceships” very good riders &c. as discussed last year)
- Other “Gölsdorf style follow-ups” (rare indeed) include Polish Ty23 2 cyl 2-10-0 built in Germany from 1923 : local constructors stunned by riding qualities still nothing done with it in Germany / elsewhere
- (240P style “no fixed wheelbase” setup compatible with 4 cyls only ← not much resistance against 2 & 3 cyl sway)

4. (Un)conventional solutions

Attendant practical measures:

- More lateral stiffness / damping in tender couplings, single frame tenders instead of bogie tenders (Gresley & Co.)
- Flexible frames? (good in *Revolution*, less so in conventional designs: causing greater motion resistance, potential fracturing &c.)
- Flange lubrication (water, grease, …)
- “Concentration” of wear on non-driving / non-coupled wheelsets → simpler & cheaper maintenanc

5. Agenda

- (Hopefully) historically of some interest but then what to do with it? → *Relevance for heritage steam traction?*
- (Existing &) newly constructed loco’s may be subtly modified, within (historical / type) approval limits
- E.g. new Clan Pacific: remove all spring loaded lateral leading and trailing bogie / Bissel control & replace it by (more) friction damping (thus including some harmless stiction as in Gölsdorf’s successful designs)
- Still better: fix the bogie pivot (Gölsdorf style), + lateral movement in leading coupled axle + thinner / no (?) flanges on driving wheels + laterally fixed trailing coupled axle. “Too much lateral movement?” Then fully flanged driving wheels + leading and trailing axle lateral movement (lateral damping on trailing Bissel only)

5. Agenda

- Doubts concerning approval (given “parental rights” &c. presupposing sufficient identity with originally approved loco type)?

E.g. *Clan*: leave the lateral springs &c. in place, reduce their force & introduce (more) mechanical friction → better damping

5. Agenda

- What's the gain in it, given relatively low heritage speeds / loads?

1. Better ride (for paying passengers as well)
2. Less flange / wheel / engine wear (cheaper &c.)
3. Less permanent way wear & tear (*idem*)
4. Lower derailment risks (*idem*, probably marginal anyway)

5. Agenda

- More advanced, e.g. *Revolution* Pacific / Gölsdorf style 2-6-4: (adjustable) hydraulic lateral damping: no more stiction (as in Gölsdorf style mechanical friction solutions)

(Design) challenge: stronger lateral damping → more stability at speed on straight track & in wide curves but slower speeds in tight curves (faster lateral wheelset movement → more counterforforce against damping (again: Gölsdorf successfully went for minimal damping)

+ other flights of fancy , e.g. "pulling" instead of "pushing" leading Bissel-like wheelset in order to minimise flange / rail friction under lateral movement (designed & applied by Busse, Denmark, late 19th century but not followed up (sign of a good idea?), &c.

Questions? *Thank you very much*!

Further reading

Chapelon, *La Locomotive à Vapeur* (volume 2, relevant translation available)

Düring, *Länderbahnlokomotiven*

Essery, *Steam Locomotives Compared*

Giesl, *Lokomotiv-Athleten*

Glaser's Annalen

…

PS Actual steam locomotive riding qualities

Eric Gill in *LNER Magazine* (1933):

“Travelling on the footplate of *The Flying Scotsman* is something like riding on an enormously heavy solid-tyred bicycle.”