Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Contact mechanics issues of a vehicle equipped with partially independently rotating wheelsets

Andrea Bracciali, Gianluca Megna *

University of Florence, Department of Industrial Engineering, via di Santa Marta 3, 50139 Florence, Italy

ARTICLE INFO

Article history:
Received 2 October 2015
Received in revised form
19 February 2016
Accepted 28 March 2016

Keywords:
AIR wheelset
Curving behavior
Wear number
Torque limiter

ABSTRACT

A recently developed novel wheelset design where individual wheels are mounted on stub axles and are connected through a shaft is described. The design may include torque limiters to partially uncouple the wheels to reduce peak longitudinal forces.

The work described in this paper is based on the analysis of the running dynamics of a library vehicle to compare conventional and new wheelset arrangements to highlight the effects of the torque limiter on wear and rolling contact fatigue (RCF) damage. The comparison is performed for a wide variety or running speeds, non-compensated accelerations and adhesion coefficients, revealing that the proper setting of the torque limiters can effectively reduce both high rail RCF damages in mild radius curves and corrugation formation and growth in tight radius curves.

Practical applicability of the solution in terms of durability of the components together with the analysis of dissipated energy in the torque limiter are shown.

1. Introduction

Independently rotating wheels (IRWs) mounted on inside frame bogies are often used in trams and in all vehicles that require a low floor arrangement. This layout is very interesting as it allows to access the wheels for maintenance just lifting one side of the bogie frame at a time, without the need to lower the wheelset or to lift the carbody up as required with conventional wheelsets.

The absence of the torsional constraint between the wheels leads nevertheless to premature wear of wheel flanges, as the bogie tends to run skewed and with one or more wheel flanges in continuous contact with rail gauge corner. The gravitational stiffness prove to be insufficient to restore the central position of the wheelsets. This evidence, clear already in the 70s of the last century, explains why no IRW-equipped vehicles are used in conventional railways.

In order to overcome this drawback allowing at same time a dramatically improved running gear maintainability, the fully passive “apparently” independently rotating wheels wheelset (AIR wheelset for short) was developed and patented [1].

Although the reader is referred to another paper [2] to get a detailed description of the solution in terms of mechanical design, it can be shortly said that it consists of two wheels supported on hollow supports by a specific arrangement of the bearings, which is able to withstand both lateral and vertical loads acting on each single wheel. This function is critical, as the absence of a conventional axle does not provide any equalization of the lateral forces acting on the two wheels. The design makes use of bearings recently developed for inboard bearings high-speed vehicles (Fig. 1).

Two versions of the AIR wheelset are available, a motor one and a trailing one. In both the arrangements, the wheels are connected by a shaft passing through the hollow supports. In the case of the trailing AIR wheelset, the connection can be made through friction torque limiters that allow finite rotations between the wheels in case the torque limit set is exceeded.

About running dynamics, the introduction of a torsionally softer shaft connecting the wheels may lead to some decay in the performances of a vehicle. In particular, the critical speed may reduce by decreasing the torsional stiffness of the axle, as shown in [3]. The running dynamics behavior of a library vehicle is described in [4], where the impact on critical speed, track shifting forces and derailment ratio L/V (or Y/Q in the European practice) for both perfect and defective track and for the classical axle, the torsionally flexible axle and the “torque limited” AIR wheelset solution are analyzed. It was concluded that the effect of the axle torsional flexibility does not affect in practice the dynamic behavior of the vehicle provided that suitable anti-yaw dampers are used. The introduction of the torque limiter was shown to be beneficial in terms of increase of critical speeds and decrease of track shifting forces.

A preliminary paper on maintenance peculiarities of the AIR wheelset will be given at the WCRR2016 congress [5] and the work

* Corresponding author.
E-mail addresses: andrea.bracciali@unifi.it (A. Bracciali), gianluca.megna@stud.unifi.it (G. Megna).

http://dx.doi.org/10.1016/j.wear.2016.03.037
0043-1648/

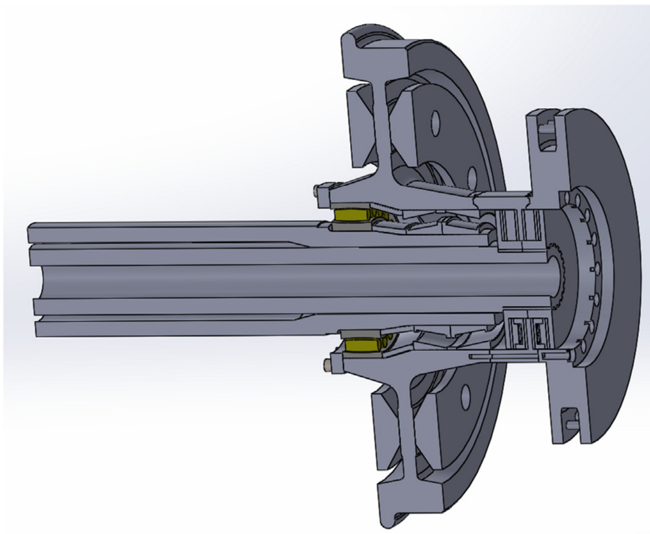

Fig. 1. Three-dimensional view of the AIR wheelset equipped with torque limiter and an optional external brake disc.

is still in progress. This activity will be developed with the help of the most important train operating company in Italy (Trenitalia SpA). It can be said at the moment that the topics that the work will concentrate on are:

- as the rotating axle "disappears", most of the conventional workshop repair activities disappear as well, as the only part subjected to maintenance is the wheel, where brake disc and bearings are fitted;
- all UT structure involved in NDT of axles (personnel, equipment, procedures) can be dismantled as well, as the stub axles are part of the bogie and will be subjected to long distance general overhaul;
- the entire logistics of the wheelset changes, as wheel change will be possible with standard and low-cost equipment in all depots without requiring the whole vehicle lift up but only the bogie frame lift up just to free the wheels flanges from the rail head;
- a centralized workshop will be able to serve many operators and there will possibly be only one main center in a country, as logistics of wheels is much easier than that of wheelsets;
- vehicle dynamics considerations force the use of oversized bearings that will very likely last "for life", similarly to street vehicles where bearings are never changed.

The present paper covers implications of torque limiters applied to the AIR wheelset on contact mechanics and wear of rail/wheel systems.

2. Forces and damage at the wheel–rail contact

The accepted parameter [6] involved in wear and rolling contact fatigue of wheel is the wear number W, also known as "Tgamma", given by Eq. (1):

$$W = T\gamma = T_x\gamma_x + T_y\gamma_y \tag{1}$$

where T is the tangential force acting on the wheel and γ is the creepage. The x and y suffixes refer to the longitudinal and lateral directions, respectively.

One potential model uses the Ekberg damage parameter [7], described by Eq. (2)

$$FI_{surf} = f' - (2AK_e)/(3T') \tag{2}$$

where T' is the vector sum of the longitudinal and lateral tangential forces T_x and T_y (Eq. (3)), A is the contact area and K_e is the shear yield strength of the wheel material. The following formula therefore holds

$$f' = T'/Q = \sqrt{{T_x}^2 + {T_y}^2}/Q \le f \tag{3}$$

where f' is the utilized friction coefficient and Q is the normal contact force. The forces at the wheel rail contact are limited by the adhesion coefficient f. Slip therefore results when the constraint is saturated, i.e. when $T' = fQ$.

The relative contribution of lateral and longitudinal forces and creepages depends in a non-linear way on the running conditions and on the architecture of the vehicle.

The use of the torque limiter in the AIR wheelset allows to manage (limit) in some way the longitudinal forces at the wheel–rail contact, leading in principle to a reduction of the T_x component and the associated γ_x creepage and therefore to a reduction of longitudinal wear number $T_x\gamma_x$. It should be said, however, that also the lateral behavior of the wheelset can be affected by this change and that different values for both lateral forces and creepages can be obtained, leading to higher $T_y\gamma_y$ wear numbers. This can be justified by the reduced steering capability of a wheelset equipped with torque limiters that leads to greater angles of attack and possibly larger lateral displacement of the wheelsets.

3. The reference case – ERRI wagon

3.1. Introduction

In order to evaluate the effects on wear and RCF of a torque-limiting device, the analysis of wheel–rail forces was conducted on a reference vehicle, i.e. the "ERRI wagon" present in the VI-Rail v. 16.0 software library [8] and used in the past as reference for a software codes benchmark [9]. It is a passenger car with two bogies equipped with anti-yaw dampers and a total of four wheelsets.

The reason and the limitations for this choice are the following:

- any possible solution found is relative to the specific vehicle chosen;
- the ERRI wagon was selected mainly as it makes possible the generation of solutions that can be easily validated and reproduced by the scientific community;
- modeling mistakes are avoided and the attention can be focused on the results, whose accuracy is indisputable;
- the ERRI wagon is representative only of a category of vehicles (long distance passenger cars) and has parameters that may differ from other category of vehicles (high speed, mass transit, metro, freight, etc.) and the results in some "extreme" situations (e.g. very tight curves with very high adhesion limit, typical of metro applications) may not be fully reliable.

Focusing on longitudinal forces T_x, the average force on the two wheels for the i-th wheelset $T_{xi,av} = (T_{xi1} + T_{xi2})/2$, i.e. the resistance to motion, has a magnitude that always remains small. Further considerations on tractive effort required in the case of standard wheelsets and on wheelsets equipped with torque limiter will be discussed later in the paper.

More interesting is the analysis of the difference of the longitudinal forces acting on the two wheels of a wheelset, $\Delta T_{xi} = (T_{xi1} - T_{xi2})/2$, as it originates: