Railway Engineering: Track and Train Interaction

COURSE SYLLABUS

Week 1: Vehicle-Track Interaction

When a railway vehicle passes over a track, the interaction between the two yields forces on both vehicle and track. What is the nature of these forces, where do they originate, and how do they influence the design and performance of the track and the vehicles? In this first week, you will find the answers to these and other related questions.

1.1 Conventional tracks

The majority of the modern railway tracks still belong to the ballast type. In this 1st hour, we answer the question 'Why is this type of track still widely used?'. The basic principles, main elements of railway track, and their functions and design will be explained. We will also discuss developments in conventional track construction over the years.

1.2 Unconventional and innovative tracks

Is it possible to build a track without ballast? What are the advantages and disadvantages of ballast-less track structures? What are the differences between various types of ballast-less track structures? How can you select the track structure that best fits a certain application? All these questions will be discussed in this 2nd hour.

1.3 Track Geometry

As a passenger, you would prefer a smooth ride in order to be able to relax and enjoy your journey. However, a pleasant ride for you does not necessarily mean a smooth ride for the train! Good track geometry is necessary to guarantee smoothness and durability. But what is considered good track geometry? Based on the dynamic interaction between track and train, the consequences of irregularities in the geometry are discussed. After this 3rd hour, you will be able to understand the role of track geometry in relation to track dynamics, track forces, and environmental vibrations.

1.4 Bogies

Wheelsets and bogies are essential elements of a railway vehicle. In this 4th hour, the construction of wheels and wheelsets and the behavior of bogies on both straight and curved track will be discussed. In addition, the basics of the dynamics of bogies will be covered. After this, you will be able to explain the principles and functions of a bogie with its key components, and of course, the principles behind steering a train.

1.5 Vehicle element and the transfer of traction forces

The need for traction, combined with slippery tracks due to sudden changes in weather conditions, is not a good marriage! This 5th hour focuses on how a train delivers tractive effort and the significance of adhesion in railways. Through a brief introduction of types and functions of rail vehicles, with an overview of vehicle construction and an explanation of forces and slip, you will be able to understand and calculate the maximum tractive effort of a train.

Week 2: Traction and Energy

One thing has never changed and will never change in transport: all forms of transportation require energy to move. How much energy do the vehicles need for a particular operation and why? Where does the energy go and how does it affect the vehicles and the tracks? How does efficiency relate to resistance during a train ride? These and other questions will be answered this week.

Resistances

In order to start and/or continue moving, railway vehicles must overcome various resistances, such as rolling resistance, air resistance, curve resistance and gradient resistance. These will all be covered in this hour. Empirical methods to determine the resistances are explained, with examples drawn from different types of rail vehicles. Do you have a brilliant out-of-the-box idea to reduce these types of resistance?

Power and traction

When there is no resistance, there is no need for power. This would be ideal to get a 0% CO2 footprint, but is this feasible? How much power does a train need and where does this power go? What is the link between train speed and traction power? How does the electrical domain relate to the mechanical domain? Some illustrative examples of trams and trains will be used to answer these questions. After the 2nd hour of this week, you will be able to analyse a run-cycle of a train. Using Newton's second law and traction/speed diagram, you will be able to calculate the acceleration, cruising, coasting and braking of a specific train.

Electric traction

First, the general scheme of the traction chain from the wheel to the power source will be applied to both diesel and electric vehicles. The main characteristics of both vehicles will be described. Practical questions, such as 'How much power does a traction vehicle require for a given situation?' will be answered.

Independent traction

Not all trains run on electricity. A significant number of trains worldwide run on independent traction systems, of which diesel is the most common type. This 4th hour covers the principles of the different types of diesel traction and also introduces traction based on hydrogen. After this hour, you will understand the basics of independent traction technology and will be able to select the appropriate type of independent traction for a railway system.

Braking systems

In this 5th hour, the function and construction of braking systems, and types of brakes will be explained. The influence of braking on vehicle performance such as braking distance will be discussed as well. Obviously, accelerating requires substantial amounts of energy. Later, when braking, this energy can be regenerated and re-used in the train or elsewhere. The principles of the re-use of braking energy will be explained here.

Extra: Ask the Professor

Throughout the course, Professor Rolf Dollevoet will be available to answer any questions you have in fortnightly videos. He will give you feedback and counter-questions as well.

Week 3: Wheel-Rail Interface

Most of the problems in railway systems nowadays originate in the wheel-rail interface, such as: broken rails, crossings, and wheels. These are the main source of disruptions in a railway network. What is at the root of all these problems? Is it possible to avoid them or reduce their negative effect and how? In this week, you will find the answers to these questions.

Hertzian contact

The contact between wheel and rail occurs on a very small area, resulting in extremely high stresses. The magnitude of these stresses defines the rail and wheel degradation, and ultimately determines the service life of rails and wheels. In the simplest case, when a vehicle is running on a straight track, the Hertz theory can be used to estimate the contact pressure. In the 1st hour of this week, the main elements of this theory will be presented. In addition, some wheel and rail sub-surface defects will be explained.

Rolling contact

Nowadays, due to the increase of the axle loads and traction power, most defects occur in the rail/wheel surface rather than underneath. Therefore, a more accurate and complex solution of the rolling contact is required to analyse these situations. Accounting for the effects of friction forces is crucial in this analysis. In this 2nd hour, more advanced theories and solutions of the rolling contact problem will be presented.

Steel defects

The lifespan of wheels and rails is to a large extent affected by the properties of their material, which is in most cases steel. Aspects like main steel properties, the rail manufacturing process, material composition, and similar factors affecting wheel and rail performance will be discussed here. Although a lot is possible from a technical point of view, the challenge here is to keep the right balance, between durability and costs.

Rail welding

Rail welds are a notoriously weak part in the rail network, where a high number of defects occur. Reducing the number of welds will thus reduce the risk of failure. Clearly, getting rid of all rail welds is impossible, since they are necessary to join the rails of a railway track. Therefore, an understanding of the characteristics of welds is essential. Welds contribute to track geometry irregularities mostly in the shortwave range. Due to this type of irregularities, high impact forces may arise because of passing trains. Dynamic contact forces may significantly affect the service life of the rails. We will further delve into the main types of welding, the mechanisms of surface degradation due to welding, and methods to prolong the service life of the rails.

Switches and crossings

One of the most important and most vulnerable elements of a railway infrastructure is a railway turnout (also referred to as switch and crossing). As an example, high forces in the crossing area result in eight unexpectedly broken frog points per week in the Netherlands alone! What is the source of these forces? How do they affect the crossing performance? How can crossing performance be improved? We will discuss all these questions in this 5th hour.

Week 4: Track-Vehicle-Pantograph Dynamics

In this week, we will look at vehicle behaviour, starting with train-track interaction in the form of hunting. Then, the pantograph-catenary system will be investigated. Moreover, vibrations at different scales will be explained, which are important for the interface with the neighbours and environment. These interactions and their consequences for the railway design as a whole will be discussed in detail.

Hunting

As trains run on a track, the wheelsets undergo an oscillating motion called hunting, which affects both vehicle and track. In the 1st hour of this week, the hunting motion and its consequences will be discussed. In addition, we will explore the effect of the wheel-rail-contact and profiles on the hunting motion (critical speed) and the bogie properties affecting hunting.

Pantograph/catenary system

Starting with a historical overview, the design and components of a pantograph/catenary system, including pre-tension, system installation and operation will be presented. Then, the main aspects of the interaction between the pantograph and catenary system, such as the dynamics and stiffness of the system, material choice (carbon/copper/silver) and wear will be explained. Although, traditionally, the contact between pantograph and catenary is gliding, there might be better solutions.

Noise

Vertical and tangential train-track interaction may result in noise, which can be very annoying, especially in populated areas. In this 3rd hour, we will be discussing various sources of railway noise, as well as its main influencing parameters and mitigation measures.

Vibration

The dynamic train-track interaction may generate environmental vibrations that can propagate through the soil and cause disturbances in surrounding buildings. Some elementary theory on mechanical vibrations and wave propagation will be introduced and applied to railway engineering. In addition, vibration mitigating measures and their working principles will be addressed.

Track elasticity

Track vertical elasticity is an important characteristic of the track and the whole track-train system. The elasticity varies along the track. In this 5th hour, the effects of the changing elasticity will be explained. Furthermore, results from the stiffness-measurement train will demonstrate stiffness distribution in a real-world case.

Extra: Forum Discussions

During the course you will also be invited to join us for problem-solving discussion on the complexity of railway systems engineering. Professor Rolf Dollevoet will take part in these interactive sessions, responding to your answers with further complications to challenge your knowledge.

Week 5: Interface with Civil Structures

Civil engineering structures, such as bridges and tunnels, are unavoidable in the railway network. Their presence also introduces disturbances in the railway system, which result in various dynamic phenomena affecting performance of the railway system. These effects must be considered when designing and maintaining the railway system.

Transition zones

The places in the railway network, where the surface or the vertical stiffness of the supporting structure abruptly changes, such as near bridges and culverts, are called transition zones. If nothing is done about these transition zones, problems will occur over time, which will make trains jump rather than roll. We will examine the main problems related to transition zones, like track settlement, their consequences and the mitigation measures.

Bridges

The need for bridges introduces changes in the properties of the vertical rail support. When building bridges, there are two main issues: 'how to build the bridge' and 'how to build rail track on the bridge'. Understanding both is necessary to successfully integrate them into a single robust bridge system. The main types of railway bridges, related problems and adjustments create complex design challenges.

Tunnels

Over the years, very large developments have been made on tunnel design. Where there were almost no regulations in the past, nowadays many safety regulations are in place, but why? Starting with an overview of the types of railway tunnels, the main requirements for the track in tunnels will be discussed. The working principles of vibration isolation will be illustrated using a floating track.

Soil

The soil provides the bearing function of the track. Thus, its properties are vital for the performance of the railway system and the service life of its components. In this 4th hour, the main requirements to the ballast and soil in railway track will be discussed. Some illustrative examples will be given.

Stations and level crossings

Can you optimise a station by altering the number of switches? How do stations and level crossings connect the railway network with the rest of the world? And what are the different functional types? In this final hour, we will explore the specifics of station design related to the track-train interface. In addition, we will explore the functions and design of level crossings, and we invite you to bring in real-world examples and future solutions.

Week 6: Case Study

We challenge you to apply your knowledge of the whole course to analyse a case study on railway design.

We challenge you to apply your knowledge of the whole course to analyse a case study on railway design. In this case, a railway line crosses five locations, each with its own challenges: level crossing, bridge, swamp, passing station and a mountain passage. For each, we will consider five possible technical challenges that might affect this ride: track structure, resistances and energy, welds, noise and vibrations and soil. The main goal is to identify the positive and negative points in this system, and to examine how to deal with the facts in a system to solve this. This systems approach to engineering will give you insight into how all the knowledge you learned is connected within the railway system.