Past and present

Extract from the Railway technical handbook, volume 1, chapter 1, page 8 to 23
1 Past and present

Energy saving ........................................ 9
Historical railway applications ............. 12
Past and present bearing designs .......... 14
Lubricant saving ..................................... 16
Present rail focus ..................................... 16
Global presence ...................................... 20
Quality .................................................. 22
Past and present

The assembly of two railway wheels and an axle is commonly known as a wheelset, which is rotating and supported by bearings that are called axlebox, journal or wheelset bearings. These bearings are housed in axleboxes or supported by special adapters that are connected to the running gear directly or via springs and in most cases designed as a bogie. Axleboxes are one of the most safety-critical sub-systems in railway vehicles.

Energy saving

The continuous development of axleboxes and bearings is part of an overall effort to reduce friction and wear as well as to save energy. Interacting surfaces in relative motion are studied through tribology science and technology, which includes the study and application of the principles of friction, lubrication and wear. The word “tribology” is derived from the Greek “tribo” meaning root, and “logos” meaning principle or logic. Excellent examples of applied tribology can be found in the transportation sector. This goes back as far as the invention of the wheel. For railways, it started with the introduction of the first railways, and later the antifriction axlebox bearings. Today, highly sophisticated axlebox bearing units and complex solution packages covering bearings, seals, lubrication, mechatronics (e.g. sensors to detect operational parameters) and a comprehensive range of services are available from SKF.

Transportation is needed every day around the globe to move people and goods. Economic and environmentally friendly passenger and freight transportation are two of today’s most challenging issues. There are different modes of transportation by water, air and land, each having specific characteristics. Most of them are part of a complex logistic system including infrastructure, vehicles and operation. Even developments in the past were very much focused on cost-effectiveness that included high energy saving goals. Human and animal power, coal for steam engines and fuel for combustion engines, as well as electricity, often had limited availability. Today, energy saving is a very important topic. This has caused people to continuously strive to develop new solutions that are energy-efficient.
Historical energy saving examples

The following pages include a selection of very early examples, showing fundamental inventions such as the wheel, railway, ball and roller bearings. These examples include their energy saving capabilities.

The wheel principle

Land transport is very much connected with the development of the wheel, which can be seen as one of the oldest and most important inventions. The first wheels were originally used in Mesopotamia (an area between the Tigris and Euphrates rivers, in Iraq, as well as some parts of Syria, Turkey and Iran) around 5000 BC as potter’s wheels. The earliest display of wheel usage was newly-discovered in 1976 in the Kraków region in Poland. The Bronocice ceramic pot was named after the village where it was found and has been dated by the radiocarbon method to 3500–3350 BC. The pot can be attributed to the funnel beaker culture.

Some later applications of the early used wheel principle can be found in Europe and Western Asia and later also in China. The main advantage of the wheel is that it saves energy.

First railways

A further development was the improvement of the wheel/road interface by using harder and geometrically optimized surfaces.

Wheel energy saving calculation example

Drag an object with a mass of 100 kg along a surface, assuming a medium friction coefficient of \( \mu = 0.5 \).

- The load = mass \( \times g = 100 \times 9.81 \) N = 981 N
- The force required = mass \( \times \) friction = 100 \( \times 9.81 \) N \( \times 0.5 = 490.5 \) N
- The energy spend = force \( \times \) sliding distance = 490.5 N \( \times 10 \) m = 4905 Nm = 4905 J

Carry the same object by a 2-axle carriage on 4 wheels, assuming a friction coefficient \( \mu = 0.1 \); the wheel diameter = 1000 mm and the axle diameter = 50 mm.

- The load remains the same: 981 N
- The force required = mass \( \times \) friction = 100 \( \times 9.81 \) N \( \times 0.1 = 98.1 \) N,
- To displace the object over 10 m, the surfaces shaft/wheel slide 10 m \( \times 0.05 \) m / 1 m = 0.5 m
- The energy spend = force \( \times \) sliding distance = 98.1 N \( \times 0.5 \) m = 49.05 Nm = 49.05 J
- The energy saving is 99%.

However, some energy is lost at the wheel to road interface. This rolling resistance is predominantly an energy loss because of deformation.

A very descriptive energy saving example is given in an illustration of the Linz / Austria – Budweis\(^1\) / Czech Republic horse railway, mainly built for the transportation of, what was then, very expensive salt. The 130 km long line was opened in 1832 and was by far the world’s longest railway connection. The illustration shows that a rail system could carry 8 to 10 times the load of a road transport\(^2\).

\(^1\) České Budějovice in Czech language

Comparison of payload transported on road with two horses and on rail with one horse

Description of the Sumerian “battle standard of Ur” (circa 2500 BC)

The “Bronocice pot” 3500–3350 BC is so far seen as the earliest display of wheel usage for a vehicle application and is stored in the Archaeological Museum in Kraków, Poland
Axlebox bearings

There are some early patents, but there is no evidence that they were really all used. One of the first well-documented antifriction axlebox bearing applications from 1903 are 3-axle passenger cars equipped with axleboxes, each incorporating two deep groove ball bearings [1]. The tractive effort for a 2-car set with a total weight of 33.15 tonnes was 4,400 N with plain bearings and 620 N with ball bearings, which is a reduction of 86%. The bearings and axleboxes were manufactured by Deutsche Waffen- und Munitionsfabriken A.G. (DWF) in Berlin, Germany. This company later became part of the Vereinigte Kugellagerfabriken (VKF), which in turn was acquired by SKF [3, 4].

A further test was conducted by Prof. Graham of Syracuse University, New York, United States in 1905. He researched energy consumption in the form of a comparison field test between two trams, the first equipped with sliding bearings and the second with roller bearings. Energy consumption of the tram using sliding bearings was 6.45 kWh; compared to 3.10 kWh of the tram with roller bearings, over the same distance – an energy saving of 52%. In 1907, the Syracuse Rapid Transit Co operator told the Standard Roller Bearing Co in Philadelphia that after four and a half years of operation and some 400,000 kilometres (250,000 miles), the roller bearings showed no wear. The annual saving in coal to generate the electrical power needed was 260 US dollars per year per vehicle, equal to 390 g gold. The Standard Roller Bearing Co later became part of the Marlin Rockwell Corporation (MRC). SKF acquired MRC in 1986 [5].

1903 DWF axlebox arrangement, incorporating two deep groove ball bearings

1903 DWF field tests, axleboxes incorporating two deep groove ball bearings

Extract from May 1909 catalogue

SRB tramway axlebox bearing used for the energy saving testing in 1905

SRB catalogue 1908

Test results from Prof. Graham of Syracuse University, New York, United States in 1905

SRB catalogue 1908
Historical railway applications

Speed has been the essence of railways since the first steam locomotive made its appearance in 1804\(^1\). SKF remains at the forefront of high-speed train application design, providing some of the most safety-critical components for railway vehicles – the wheelset axlebox assemblies, comprising the wheelset bearings or units, the axlebox housing and integrated sensors. SKF has always been active in developing, designing and testing wheelset bearings to meet the challenging requirements of high-speed train manufacturers and operators. By the 1930s, trains in Europe and North America had already reached travelling speeds of 130 km/h, with top speeds of 160 km/h. Today, high-speed rail transport is defined in some European standards as vehicles with a maximum speed of more than 200 km/h\(^6\).

\(^1\) The first full scale working railway steam locomotive was built in 1804 by Richard Trevithick (1771 – 1833) in the United Kingdom.
In the 1930s, Michelin developed the rubber-tyred Michelin 23 vehicle to launch their pneumatic tyres. The specific vehicle mass per passenger could be reduced from around 950 kg for a typical bogie car to 170 kg for the Michelin 23 vehicle, by using new mass-saving technologies from car and aircraft design. The vehicle was 30.36 m long, max. speed 150 km/h.

The Swedish railways used the class F electric locomotives for their Stockholm – Malmö and Stockholm – Göteborg lines, power rating 2 600 kW, max speed 135 km/h.

In 1938, the Chilean railways ordered diesel electric multiple units from MAN in Nürnberg, Germany, to serve on the long distance 1 676 mm broad gauge lines to Santiago with an operating speed of max. 130 km/h, SKF Ball Bearing Journal 4/1941.

Axlebox for non-powered front and rear wheelsets incorporating two spherical roller bearings mounted on a withdrawal sleeve, SKF Ball Bearing Journal 2/1944.

Front bogie axlebox incorporating two spherical roller bearings mounted on a withdrawal sleeve, SKF Ball Bearing Journal 4/1941.

Rubber-tyred vehicle equipped with two tapered roller bearings, SKF Ball Bearing Journal 1/1939.

Axlebox for powered wheelsets incorporating two spherical roller bearings mounted on a withdrawal sleeve.
### Past and present bearing designs

**Axlebox bearings**

<table>
<thead>
<tr>
<th>Deep groove ball bearings</th>
<th>Self-aligning ball bearings</th>
<th>Needle or long roller bearings</th>
<th>Cylindrical roller bearings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td>1903: One of the first axlebox applications by DWF, Germany (later acquired by SKF)</td>
<td>1907: Invented by Sven Wingquist, Sweden (later SKF), 1911 first SKF axlebox application</td>
<td>1905: One of the first axlebox applications by SRB, USA, (later acquired by MRC, which was taken over by SKF)</td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td>Arrangements incorporate one or two bearings</td>
<td>Typical arrangements incorporate two bearings</td>
<td>Typical arrangements incorporate one bearing, full complement bearing design (without a cage)</td>
</tr>
<tr>
<td><strong>Present status</strong></td>
<td>Historical relevance only, replaced by roller bearings because of higher load carrying capacity</td>
<td>Historical relevance only, replaced by spherical roller bearings because of higher load carrying capacity</td>
<td>Historical relevance only, replaced by other roller bearings with cages</td>
</tr>
</tbody>
</table>

**Introduction**

- 1903: One of the first axlebox applications by DWF, Germany (later acquired by SKF).
- 1907: Invented by Sven Wingquist, Sweden (later SKF), 1911 first SKF axlebox application.
- 1905: One of the first axlebox applications by SRB, USA, (later acquired by MRC, which was taken over by SKF).
- Around 1920: launched by SKF – Norma (Germany), FAG and some other companies.

**Design**

- Arrangements incorporate one or two bearings.
- Typical arrangements incorporate two bearings.
- Typical arrangements incorporate one bearing, full complement bearing design (without a cage).
- Typical arrangements incorporate two bearings.

**Present status**

- Historical relevance only, replaced by roller bearings because of higher load carrying capacity.
- Historical relevance only, replaced by spherical roller bearings because of higher load carrying capacity.
- Historical relevance only, replaced by other roller bearings with cages.
- Used for new vehicles based on existing designs, trend is to replace it with cylindrical roller bearing units with integrated seals.
## Roller bearing units

<table>
<thead>
<tr>
<th>Roller bearing units with integrated sealing system</th>
</tr>
</thead>
</table>

### Spherical roller bearings
- 1919: Invented by SKF
- Arrangements incorporate one or two bearings
- Today, only bearing replacement during maintenance, alternatively replaced by tapered roller bearing units with integrated seals

### Tapered roller bearings
- 1925: Launched for axlebox applications by Timken, USA
- Typical arrangements incorporate two bearings mounted face-to-face or back-to-back
- Today, some bearing replacement during maintenance, otherwise replaced by tapered roller bearing units with integrated seals

### Tapered roller bearing units
- 1954: Developed by Timken
- Arrangements incorporate two tapered roller bearings with a common outer ring, integrated seals riding on seal wear rings
- For new vehicles and new designs, replaced by compact tapered roller bearing units with integrated seals

### Cylindrical roller bearing units
- 1995: Launched by SKF
- Arrangements incorporate two cylindrical roller bearings, the seals ride on the inner ring land
- Design replaces arrangements with standard cylindrical roller bearings

### Compact tapered roller bearing units
- 2000: Launched by SKF
- Arrangements incorporate two tapered roller bearings with a common outer ring, the seals ride on the inner ring land
- Preferred design for speeds up to 160 km/h
Lubricant saving

In addition to saving energy, reducing lubricant consumption can contribute to reducing environmental impact. Bearing lubricants such as oil and grease have to be refined from mineral oil. During maintenance, after many years of service, the used lubricant has to be collected during axlebox dismounting and disposed of as chemical waste, just like other used mineral oil-containing products. It is obvious that minimizing the quantities of lubricant used provides a positive contribution to the environment.

Oil lubrication

Oil-lubricated plain bearings were used in the early years of rail transportation. The initial oil fill of a typical German freight car in the axlebox was 1,300 g, of which 500 g were used for the oil pad lubrication and 800 g for the oil reservoir. The oil level had to be checked very frequently, as the continuous oil loss during operation heavily contaminated the railway tracks and the environment. The oil consumption was around 200 g / 1,000 km.

Grease lubrication

A major step forward was the introduction of grease-lubricated roller bearings. The grease fill is applied during the mounting procedure. For most applications, no further relubrication is needed. In the 1930s, the grease quantity of a typical German freight car axlebox fitted with cylindrical roller bearings was around 1.7 kg. Research over the years has confirmed that the lubricant quantity could be dramatically reduced without risking lubricant starvation. Around 1950, the grease quantity was reduced to 1.2 kg, later to 1 kg, and today to 0.7 kg for lubrication of open cylindrical roller bearings. A further major step in reducing grease consumption was the introduction of a sealed and pre-lubricated cylindrical roller bearing unit (CRU) where only 0.2 to 0.3 kg grease is needed. The reduced grease quantity results in a lower operating temperature. This leads to a longer grease and service life.

Present rail focus

High-speed development

Today, high-speed trains, cruising at 300 km/h, have changed Europe’s geography, and distances between large cities are no longer counted in kilometres but rather in TGV, ICE, Eurostar or other train hours. The dark clouds of global warming threatening our planet are seen as rays of sunshine to this most sustainable transport medium, with other continents and countries following the growth path initiated by Europe and Japan. High-speed rail represents one solution to sustainable mobility needs and symbolizes the future of passenger travel.

Evolution of the world high-speed network, source UIC

Grease quantity of a typical German freight car axlebox
Present bearing designs
There is an ongoing worldwide trend to use more and more ready-to-mount factory pre-lubricated bearing units with an integrated sealing system on both sides. These units simplify the mounting process dramatically and contribute to higher reliability and safety. This is because maintenance of these units is moved to re-manufacturing divisions of bearing suppliers or other independent specialized facilities.

These axlebox bearing units can be based on tapered or cylindrical roller bearing units. Both systems have unique advantages and are successfully used in all kinds of railway vehicle applications (chapter 4). Many railway operators and manufacturers have strong preferences for the design to be used and trust to their well-established operational and maintenance knowledge and experience.

Early tapered roller bearing units had a garter sealing system riding on special seal wear rings that required an additional length of the axle journal. The next development step, already introduced, was to integrate the sealing system into the bearing and to mount seals that ride directly on the inner rings. These compact designs have a much narrower width and a shorter axle journal can be used. This contributes to reduced bending under axleload and offers a lot of advantages as described in chapter 4.

Using polymer bearing cages, instead of steel or brass ones, can significantly contribute to higher reliability and safety. This introduction process, supported by extensive laboratory and field testing, is becoming to be nearly complete, and except for some unique cases, the polymer cage is the standard design.

The sealing system is constantly under development. Newer designs are being implemented to reduce friction and operating temperatures, resulting in longer grease life and maintenance intervals.

Bearing units
Axlebox bearing units are factory pre-lubricated and fitted with either contacting or non-contacting high performance seals. This design provides, in many cases, a much longer SKF rating life. This calculation is based on the load conditions, the reliability and the SKF life modification factor that takes the lubrication condition and level of contamination during operation into account (chapter 5).

Because of the grease performance, limitation of field service life has to be considered.
SKF solution packages

For over 100 years, SKF has become synonymous with advanced bearing technology and is the world’s leading supplier to the railway industry. Adding to this solid knowledge base, SKF is also a leading supplier of products and solutions within mechatronics, lubrication systems, seals and services for various applications.

The present and future delivery scope comprises the axlebox bearing unit including sealing systems and the tailor-made axlebox, as well as mechatronic system solutions to measure operational parameters and to monitor the bogie condition. Lubrication systems include wheel flange lubrication solutions to reduce friction and wear between wheel and rail. Service packages are tailored to the manufacturers’ and operators’ needs, including testing, mounting, global after-market sales and service, remanufacturing and logistic services. SKF offers a unique worldwide network of sales, application and service engineers to work closely with manufacturers and operators on international projects (→ page 20).

Bearing packages:
- tapered roller bearing units (→ page 77)
- cylindrical roller bearings and units (→ page 89)
- spherical roller bearings (→ page 97)

SKF Axletronic sensors (→ chapter 7)

Sensor capabilities:
- rotational speed (→ page 140)
- direction of rotation (→ page 142)
- distance measurement “odometer” (→ page 144)
- bearing operating temperature (→ page 148)
- vertical/lateral vibration (→ page 149)
AMPEP high performance plain bearings (→ page 165)

Bogie condition data transmission, monitoring and management (→ page 154) (→ page 160)

Bogie condition monitoring (→ chapter 8)

Gearbox and traction motor bearings

Wheel flange lubrication (→ page 176)
Global presence

SKF has established a global network to be close to the customers (→ page 6). This unique global railway network comprises sales, service and application engineers to work closely with manufacturers and operators on domestic and international projects.
SKF global presence

Countries in blue colour with SKF railway sales and application engineers

In most of the countries in grey colour, SKF is represented through authorized distributors/dealers.

- Railway manufacturing units
- Railway remanufacturing units
Quality

SKF pursues a systematic and disciplined approach to achieve radical improvements in all business processes, with improved customer satisfaction as a primary goal. Continuous improvement is achieved by using Six Sigma methods and toolboxes as well as the Manufacturing Excellence programme.

Six Sigma

SKF Six Sigma is a continuous improvement programme within SKF that targets waste and defects in all business processes. SKF Six Sigma projects are run by extensively trained Black Belts and Green Belts. There are a number of tools and methodologies within the SKF Six Sigma programme, ranging from traditional DMAIC and Design for Six Sigma to Lean and other waste reducing methodologies. The foundations for SKF Six Sigma improvements are fact-based and sustainable and contribute to the business objectives.

Design for Six Sigma (DFSS)

A methodology that focuses on developing new products and services to the market with optimal performance levels.

Lean Six Sigma

A methodology that combines tools from both Lean and Six Sigma. Lean focuses on increasing speed and reducing waste. Six Sigma concentrates on variation and quality – the result is faster with better quality.

Six Sigma for Growth

A customer focused approach that targets improvements in growth areas such as marketing, sales and distribution.

Transactional Six Sigma

Focuses on people processes such as service, sales and human resources.

Manufacturing excellence

SKF Bridge of Manufacturing Excellence focuses on reducing waste and eliminating non-value adding activities. SKF bases this bridge on the following five principles:

- Standardized way of working
- Right from me
- We care
- Demand driven flow
- Continuous improvement

The heart of the system is the people in the production process, who use these principles everyday to continuously improve their work.

Certificates

SKF quality is documented by relevant quality certificates, based on international standards and customer approvals. The following page contains a selection of relevant certificates of the SKF Group and the SKF Railway Business Unit. Additional certificates pertaining to SKF railway sales and manufacturing units can be submitted to our customers on request.
ISO 9001 quality management system certificate for the SKF Railway Business Unit

ISO 14001, OHSAS 18001 management system standards certificate for the SKF Group

ISO/IEC 17025 certificate for the SKF Engineering & Research Centre, Nieuwegein, The Netherlands, about the capability to generate technical valid results

IRIS International Railway Industry Standard certificate for the SKF Railway Business Unit, which has become one of the first companies to gain the IRIS certification

EN 15085-2 welding quality organization certificate for SKF France, product division axleboxes

AAR certificate about the conformity of the SKF quality assurance programme

German DB Outstanding Q1 certificate for quality capability

French SNCF AQF2 unconditional quality certificate

Russian unconditional approval for CTBU 130 × 250 × 160
The Power of Knowledge Engineering

Drawing on five areas of competence and application-specific expertise amassed over more than 100 years, SKF brings innovative solutions to OEMs and production facilities in every major industry worldwide. These five competence areas include bearings and units, seals, lubrication systems, mechatronics (combining mechanics and electronics into intelligent systems), and a wide range of services, from 3-D computer modelling to advanced condition monitoring and reliability and asset management systems. A global presence provides SKF customers uniform quality standards and worldwide product availability.

References