Thermal behaviour of an axle gear set

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Context: Improving the efficiency of truck axles

As fuel consumption is a major issue for the truck industry, the power losses of the axle are investigated. The main component of the axle is **a hypoid or a spiral bevel gear set**, which is an important source of **friction losses**.

Since **the properties of the lubricant film** at the gear contact depend on the temperature, it is important to know **the thermal behaviour** of the axle: the losses generated by the other components can locally influence the oil viscosity.

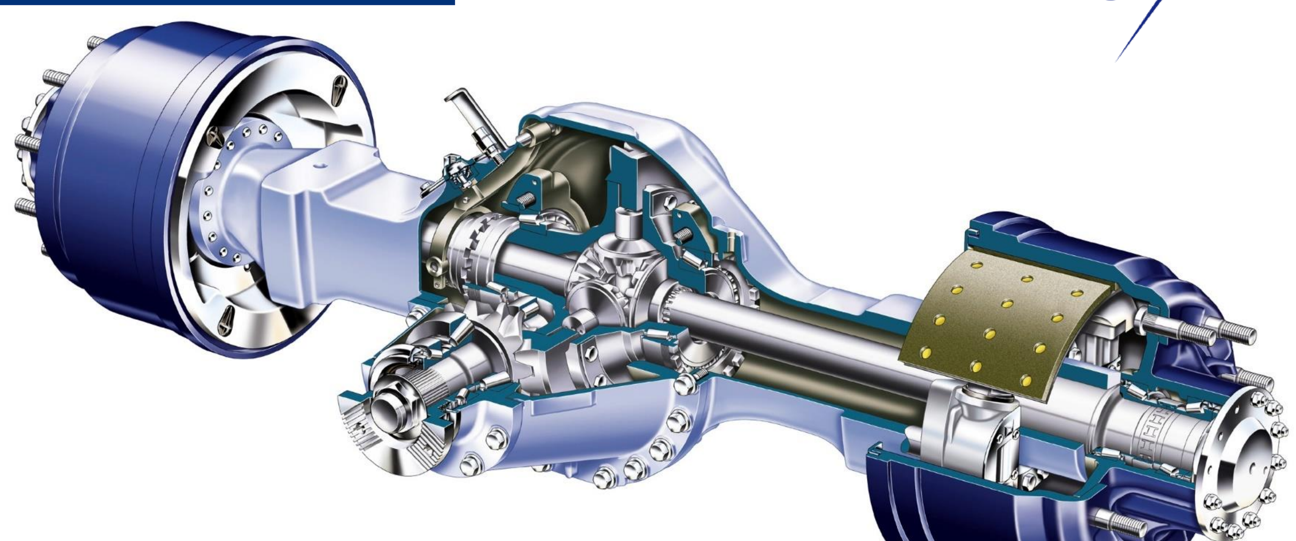


Figure 1: Truck axle

Thermal modelling of a truck axle

The **thermal-networks method** [1] is used on the axle:

- The network is composed of **isothermal elements linked by thermal resistances** based on a generalization of Ohm's Law as: $\Delta T = R \times Q$, with ΔT the temperature difference, R the thermal resistance and Q the heat flow. The used network is shown on the Figure 2 below:

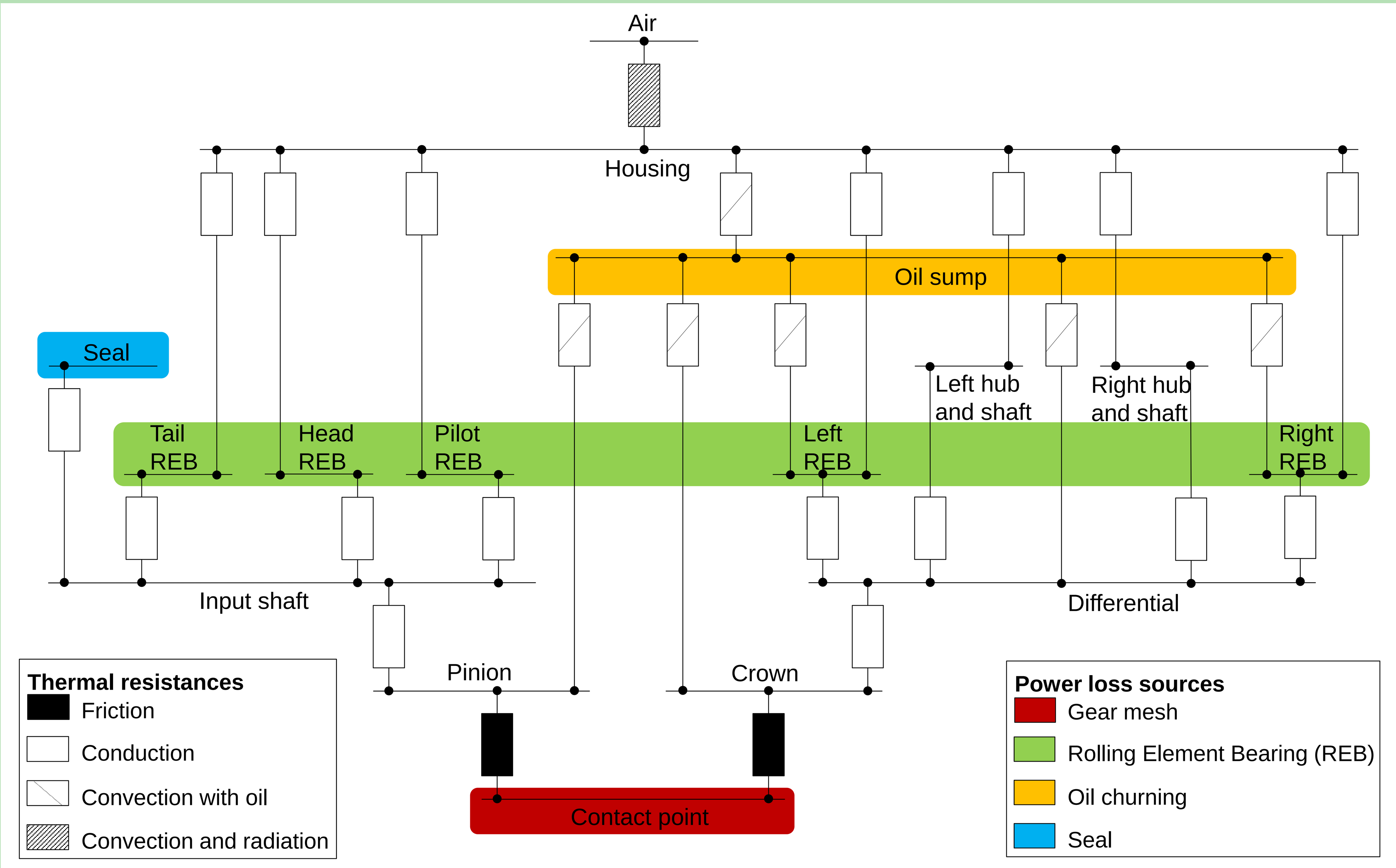


Figure 2: Thermal-network of a truck axle

- The heat generated by power losses is injected on the corresponding nodes of the system and **temperature at each node is computed**. Power loss sources considered are:
  - Gear set friction at the meshing point [2]
  - Rolling Element Bearing (REB) friction and drag force [3]
  - Oil churning by the crown gear [4]
  - Shaft seal friction [2]
- First results of this model are exposed in the following parts (see Figures 3 and 4).

Thermal mapping of the axle

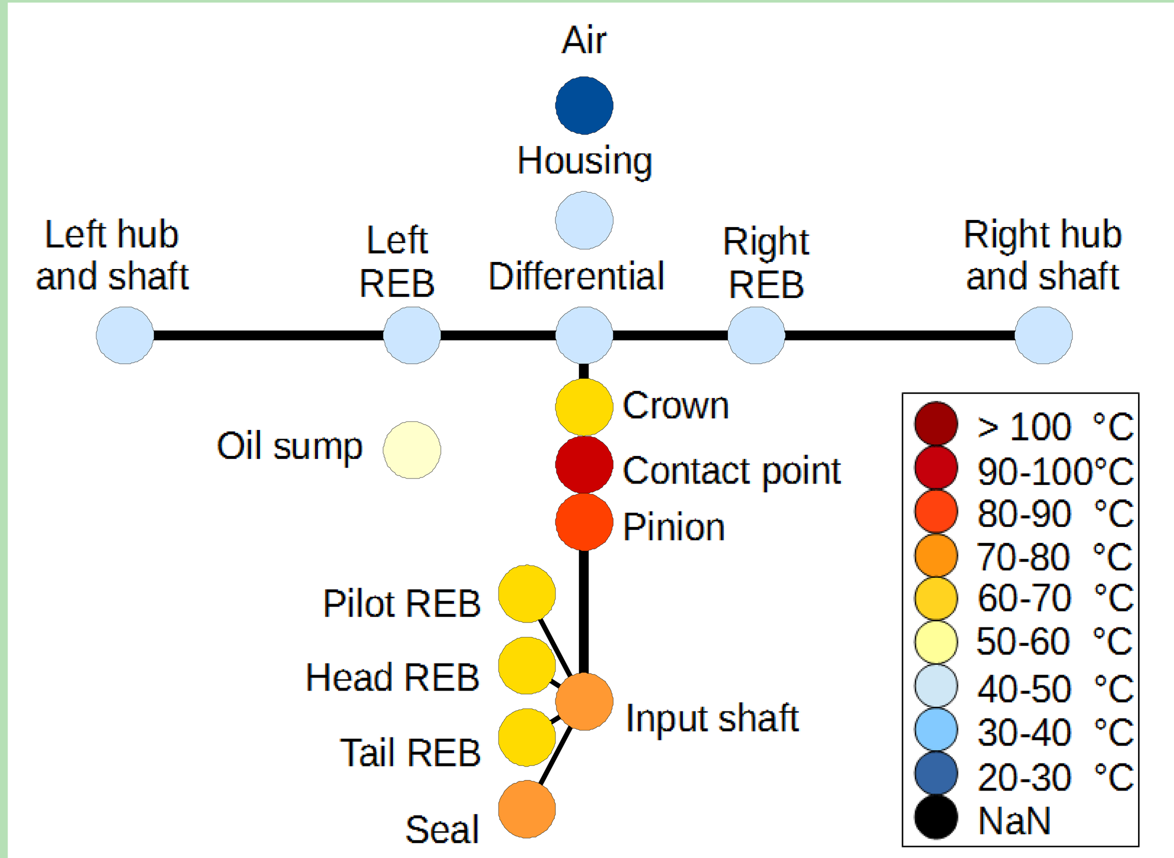
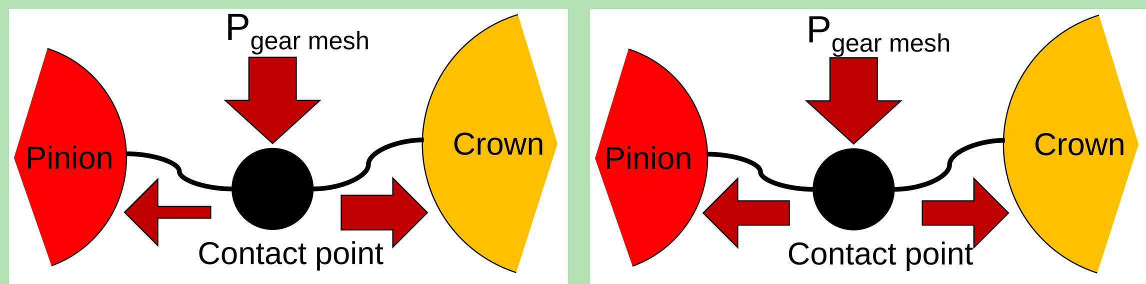


Figure 4: Computed temperatures at the different nodes of the thermal-network of the axle (at input speed 1580 rpm and input torque 725 N.m)

It is important to notice that **the elements are at different temperatures**, which is not the oil sump temperature. This modifies the oil viscosity and thus the power losses. This thermal influence is already taken into account for the REBs and the oil churning.

An interesting behaviour of the system can be observed: the elements located on the input shaft reach higher temperatures than the ones associated with the output shaft. This generates **an unbalanced heat flow from the contact point to the pinion or to the crown:** around ¾ of the heat goes to the crown.

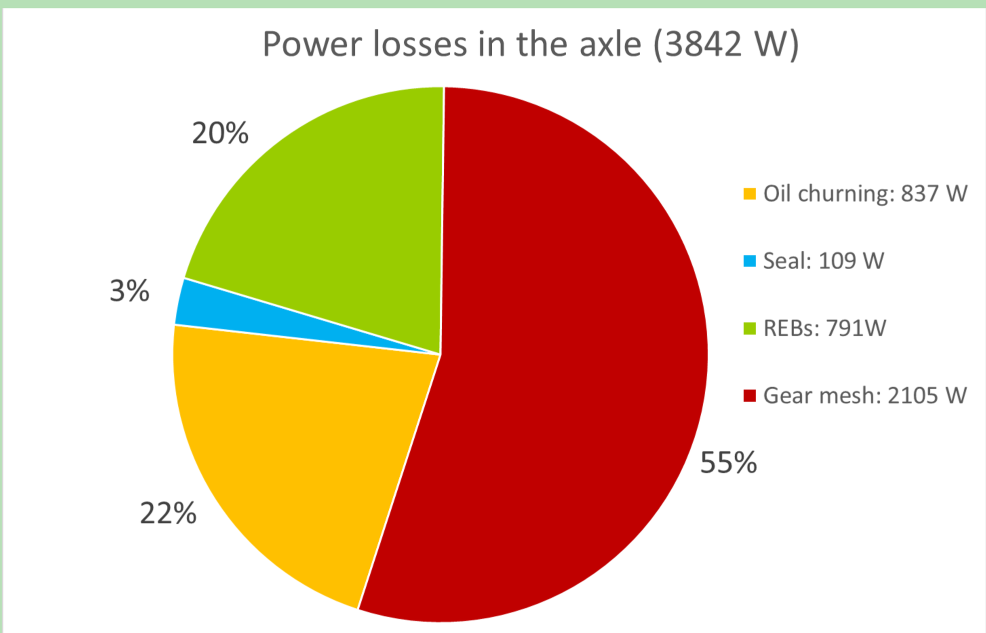


Element	¼ to the pinion ¾ to the crown	½ to the pinion ½ to the crown	ΔTemperature
Pinion	83°C	99°C	+16°C
Crown	69°C	63°C	-6°C
REBs on input shaft	68°C	74°C	+6°C

Figure 5: Comparison between the calculated repartition and the equal repartition of the heat flow from the contact point

If an assumption of equal repartition of the flux is used (standard tribology approach in contact point), an error can be done on element temperatures (see Figure 5).

Power loss distribution



As expected, **the main source of power loss is the gear set**. But Rolling Element Bearings and oil churning must not be neglected in terms of dissipation.

The total of the power losses is of the order of the one measured during previous efficiency tests (~4kW of power losses).

Figure 3: Computed power losses in an axle running at 1580 rpm and 725 N.m (input speed and torque)

Conclusion and future work

- A rough thermal mapping of the axle is computed. Thanks to it, a strong coupling between temperatures and power losses is realised. Thermal behaviour tests of a truck axle will be done in order to correlate the thermal-networks modelling.
- The gear set is actually the main source of power losses. A more precise friction law developed by Diab *et al.* [5] will be implemented in the thermal model. It will be validated by a series of friction characterization tests.

→ This will allow to evaluate the influence on friction loss of the gear parameters: shaft-offset, spiral angle, cutting method…

References

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