Safety of the shaft-wheel assembly of electric locomotives

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Abstract. Shafts of electric locomotives are exposed to complex normal and tangential stresses during its exploitation. These stresses could have extremely high level producing the breakage of the shaft. It is well known that shafts have much longer service life than wheels. However, since the stresses in shaft’s material are high, it is possible to micro-cracks appear and propagate until the shaft’s breakage. The breakage of the shaft may cause the great human and material losses. Because of that, during manufacturing these assemblies it must be taken into account all parameters which can initiate shaft crack. Geometric measure of seating and shaft are recommended by UIC regulations having great influence to quality and safety of realized assembly. The influence of contact surfaces and their lubrication during manufacturing the shaft - wheel assembly is shown in this paper.

1. Introduction
The safety of railway trains is largely dependent on the shaft-wheel assembly. For passenger’s and freight’s railway cars having not its own power, the bending stress is dominated in axle’s material under load. For traction rail vehicles (e.g. electric locomotive), shafts are loaded with bending and twisting stresses due to the static and dynamic loads \[1\]. Due to the complex stresses, the special attention must be paid in manufacturing of individual elements of these assemblies and their assembling \[2\]. At the initial moment of motion and stopping of the train there is a significant impact load. Due to this complex load, the UIC regulations require the regular control of these assemblies and the written evidence of it is obligatory. Due to the irregular control and improper detection of changes of the shaft a serious railway accident can be happen, with human and material losses as the consequences. By the statistical monitoring it has been found that the fractures often occur at the beginning of motion of the locomotive, due to extremely high tangential stresses in the shaft, especially when the composition is heavy loaded. An example of dynamic fracture by which some material losses were made, but fortunately there were no human losses, is shown in Figures 1 and 2, \[5\], \[7\]. The fracture usually occurs between the wheel hub and the driver gear. In addition to shaft fracture, some disturbance of the solid assembly between wheels and shaft can happen, that is slipping between the inner contact surface of the hub and the fitting surface on the shaft. To avoid this, the technological process of mounting of that assembly is very important. Technical service life of the shaft can be up to 45 years and more, while the service life of the wheel is significantly lower, just between 5-10 years, depending on the kilometers traveled \[8\].
2. The shaft-wheel assembly

In order to ensure a safeness of the shaft-wheel assembly, technological preparation of geometrical and other parameters before mounting is very important. It is important to establish that there are no micro-cracks on the shaft, as well as geometric dimensions and parameters are technological achieved at the press fit of shaft and wheel. Also, prescribed geometric measures and technological parameters must be checked at the inner surface of the wheel hub during machining of these surfaces. UIC regulations define indicative parameters to be followed in the preparation and realization of press fit of wheel-shaft assembly. However, micro-technological parameters for the realization of press fit are manufacturer’s secret knowledge that are difficult to be found because they significantly affect to safety and reliability of the assembly. The newly formed shaft-wheels assembly is shown Figure 3.

The quality check of the resulting press fit is performed by measuring the electrical resistance and force-displacement dependency. Electrical resistance for the new assembly (new shaft and new wheels) must be less than 0.01 $\Omega$, while for the assembly composed by an old shaft and new wheels...
wheels electrical resistance must be less than 0.1 Ω. In the force-displacement diagram, curve gradient must always be rising except at the position of oil supply channel for dismantling of shaft-wheels assembly and at the end of mounting [9].

2.1. Realisation of the press fit
General dependence between force and displacement during realisation of the press fit is shown by curves in Figure 4.

![Figure 4. The force - displacement dependence of the shaft-wheels press fit [5]](image)

The shape of the curve is affected by many parameters such as: the parallel alignment between contact surfaces, roundness of wheel hub and shaft, roughness of contact surfaces, direction in which the surfaces is realized in machining process, the quantity of lubricants and its distribution and the thickness during assembling. These parameters have a special significance for the realization of a safe assembly regarding the prescribed force-displacement curve shape, because they considerable impact on the rate of change of curve gradient. Deviation of curve gradient is permitted only at the position of oil supply channel [3]. The outer surface of wheel is coated with heat-activated color (used for daily visual inspection) that changes its shade when thermal-stresses appear in the wheel-shaft press fit that is slipping between contact surfaces. Thus, in the daily visual inspection of these assemblies, if change of the shade of the heat-activated color is detected on the surface of wheels, the electric locomotives should be excluded from traffic. After that, it is necessary to send it to the nearest authorized service workshop for detection and removal of defects.

3. Pressing force
Limit values of the pressing force are defined from empirical equation (1)

\[ F = D \cdot K \]  

(1)

where:

- \( D \) - a shaft diameter at the hub seat in [mm],
- \( K \) - intensity of 3.5 to 6 kN/mm.

Minimum value of the pressing force is \( F = 3.5 \cdot D \) kN, while maximum value is \( F = 6 \cdot D \) kN. If the force value is out these limits, than assembly must be dismantled, potential faults removed and assembly once again pressed fit [6]. Beside this, if residual stresses in assembly are out of permitted values, than shaft-wheel assembly should not be built in locomotive. Because of this, it is necessary to start with investigation and definition of lubricant’s parameters influencing to press fit process.
Theoretical dependence of the pressing force is given by equation (2)

\[ F = \pi \cdot s \cdot E \cdot l \cdot \tan \alpha \left( \mu_p + \tan \alpha \right) \left( 1 - \psi_e \right) \]  

(2)

where:
- \( E \) - elastic modulus
- \( \alpha \) - the half cone angle
- \( l \) - length of the active assembly block
- \( \mu_p \) - coefficient of stickness
- \( \psi_e \) - the ratio of diameter \( d / D \).

Since the coefficient of friction is dependent on a few parameters, it is necessary to investigate these parameters that is its influence to press fit process.

4. Experimental research

The aim of experimental research is to investigate the impact of lubricants on the pressing force curve gradient. Lubrication is carried out with a lubricant MoS₂. Speed of pressing is 50 [mm/min]. Other geometric and technological parameters are within the limits allowed by the regulations. Press fit is performed on the press intended exclusively for pressing of shaft assemblies for railway vehicles. Press is controlled by software which records the force-displacement curve in the real time. The recorded data is stored in a database. Force-displacement diagram can be printed in the form as shown in Figures 5 and 6. The curve flow in the force-displacement diagrams shown in Figures 5 and 6 satisfies. The lubricant MoS₂ is used in the anticipated amount, measured electrical resistance of the assembly meets (it is far less of permitted value). Maximal generated forces are equal. Jump of the force at the end of displacement of the first wheel-shaft assembly on the side of the driving gear, Figure 5, is caused by the contact between wheel hub and gear hub. However, changing in the amount of lubricant and its distribution on the contact surface leads to the pressing force below permissible limits, Figure 7.

\[ \text{Electric resistance } 0.00003 \, \Omega \]

Figure 5. Diagram of the press fit of the shaft and wheel A
Assembly is dismantled and visual inspection showed there is no mechanical faults. Pressing process with defined amount of lubricant distributed properly on the contact surface is done again, Figure 8. Pressing force is about 900 kN.
One can conclude from force-displacement diagram, Figures 7 and 8, that the amount and distribution of lubricant have a significant influence on a quality of shaft-wheel assembly.

5. Conclusion
Research shows that in order to achieve quality and safe shaft-wheel assembly, lubrication of contact surfaces has an important role in the technological process of assembling. The lubricant’s quantity and distribution must be within limits that have been established by theoretical research and experimental verification of these studies. In order to properly distribute the lubricant it is essential to monitor the pressing process in real-time by monitoring the force-displacement curve gradient on the machining system monitor. Any change in lubricant distribution affects the force-displacement curve gradient. The other parameters of assembly parts must be within calculated limits too.

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