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Experimental Analysis of Stress State and Motion of Tram Gearbox Hinge

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Abstract. During working of tram the chassis are dynamically loaded through acceleration, deceleration, passage curves and evidently by the roughness of the rail track. These added dynamic loads can significantly increase wearing of the chassis components and drive. In the case of tested tram problems with bearing housing into gear box occurred. Too rigid hinge bedding can cause additional parasitic load to bearings. It is desirable to investigate its stress state during acceleration, deceleration and other common drive regimes. For this purpose, strain gauges are used. Moreover, for the verification and better description of gearbox suspension behaviour, the Qualisys system for capturing and evaluating motion is used. Acquired data are processed in software Matlab and in user interface of the Qualisys software.

Introduction

During working of tram the chassis are dynamically loaded through acceleration, deceleration, passage curves and evidently by the roughness of the rail track. These added dynamic loads can significantly increase wearing of components of the chassis and drive or it can cause damage of some parts. Thus all the components have to be designed with respect to given conditions. In this case, problems with bearing mounting into gear box occurred after relatively little amount of driven kilometres in almost all gearboxes. One of the hypothesis, which can explain this problem, is too rigid suspension of the gearbox. The hinge doesn´t allow sufficient movements of the gearbox and generated reaction forces are transferred to the bearings of the output shaft as an additional load. Therefore testing of the gearbox hinge was suggested. The aim of the measurement is to analyse behaviour of tram gearbox and its hinge during the real driving conditions.

Tested tram is partially low-storeyed tram. It has three tractive chassis and it can reach the maximum speed of 60 km/h. Each chassis has two tractive mounted wheels, which are driven by partially spring-mounted drive. That consists of asynchronous motor of power 90 kW and two-gear reduction gearbox connected with claw coupling. Big gear of the gearbox is pressed on the axle of the mounted wheels, which is imbedded into bearing units. Their connection with the frame provide four rubber-metal cone springs, that create the primary springing of the tram chassis.

Hypothesis

The gearbox is furthermore connected to the chassis frame through the vertical gearbox hinge. The hinge catches reaction force generated by the rotation moment of the mounted wheels, but it has to allow some specific movements of the gearbox. The maximal tensile force in the hinge for the two-gear gearbox for quasi-static (without respect to the inertial forces of gearbox) can be calculated as

$$S = \frac{M_M(i_c - 1)}{n} \tag{1}$$

where M_M is maximal torque of the asynchronous motor, i_c is gear ratio of the gearbox and n is distance between the output shaft and the hinge axis.

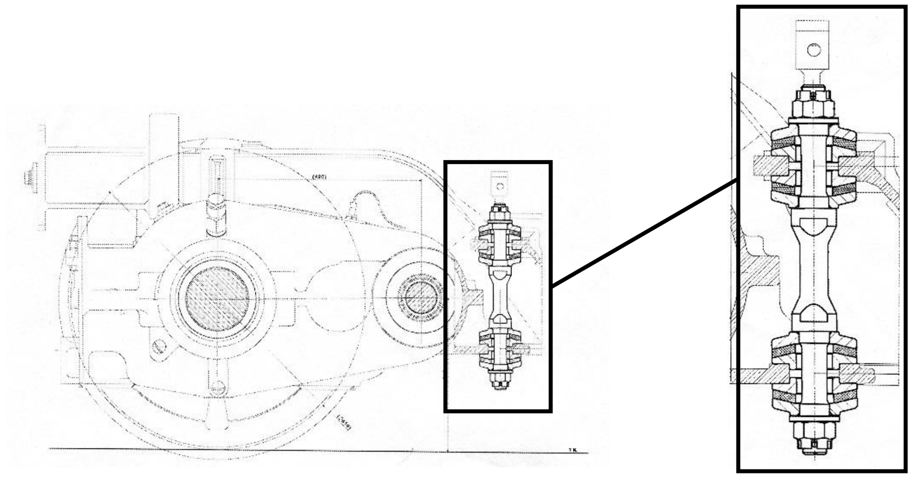


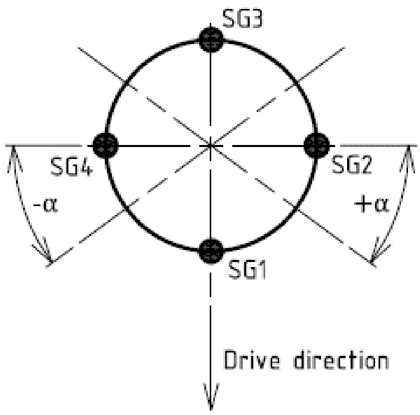
Fig. 1. Gearbox hinge design [3].

The hinge of tested tram is designed as a round bar of diameter 28 mm imbedded into rubber supports as it is shown in Fig. 1. These should behave nearly as an ideal spherical joints so the hinge can catch only tension or pressure force. Any bending stress in the hinge is parasitic because it is caused by lateral forces which produce undesirable additional radial and axial loading forces for bearings of the output gearbox shaft.

Instrumentation

As was written above the hinge should transfer only tension or pressure forces. It is desirable to investigate its stress state. Specifically tension or pressure which are expected and bending stress which is undesirable but it can confirm the above mentioned hypothesis.

Strain Gauges. Foil strain gauges are used to investigate stress state of the hinge. It is necessary to measure tension - pressure and bend simultaneously. Moreover the bend has to be find out in two perpendicular planes to obtain complete knowledge of the bend and the resultant including its orientation. For measuring tension-pressure Wheatstone half-bridge arrangement has to be used due to bend compensation. For measuring bend similar arrangement has to be used due to tension-pressure compensation. To decrease quantity of strain gauges new arrangement is designed (Fig. 2.). Only four strain gauges are connected into four independent Wheatstone quarter-bridges with time synchronization. This arrangement is very convenient because it is possible to measure tension-pressure like with full-bridge arrangement and simultaneously measure bending in two perpendicular planes like with half-bridge arrangements. Acquired signals are obtained as a strain from each strain gauge and they can be assembled after measurement like in corresponding Wheatstone bridges by means of well-known formulas.



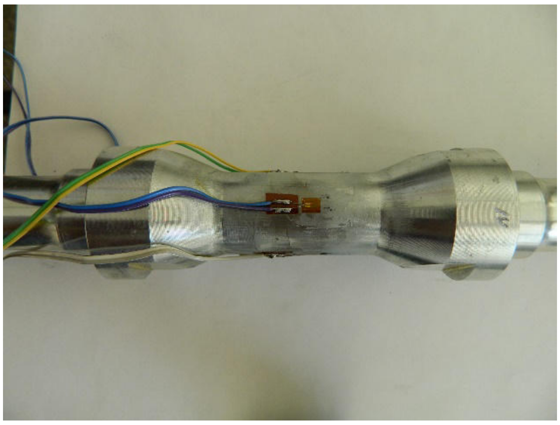


Fig. 2. Measuring arrangement of the strain gauges on the gearbox hinge.

Qualisys System. In addition to measuring stress state of the hinge it is convenient to monitor relative motions of the gearbox to the frame of the chassis and to the asynchronous motor. Then it is possible to evaluate relative shifts and rotations of the output shaft of the asynchronous electromotor to the input shaft of the gearbox and required range of motions of claw coupling. For this purpose optical system for continual capturing and evaluating motions Qualisys is used.

Fig. 3. Markers of the system Qualisys placed on the gearbox and the asynchronous motor.

Fig. 4. System of Qualisys cameras mounted to the holder.

Data Acquisition, Processing and Evaluation

The test drive was divided into three regimes – maximal acceleration, maximal deceleration and common drive. The hinge with installed strain gauges and thermal sensor was mounted into rear mounted wheel of the rear chassis of tested tram. In addition to stress and motion measurement, the torque of two asynchronous motors mounted to the chassis was recorded from the control unit of the tram. Data acquired by strain gauges contained lot of noise. That's why low-pass linear filter with Hamming's window was applied to reduce it. Script calculates tension, bend in two perpendicular planes and resultant with its orientation from data acquired from four independent Wheatstone quarter-bridges. Data captured by the Qualisys system were processed in user interface of Qualisys software. The main aim of this experiment is to detect presence of a bend in the hinge during test drive regimes. Tensile stress can be used as a verification with analytical tensile stress in the hinge. Tensile force in the hinge is calculated according to the formula (1). For the diameter of the hinge 28 mm tensile stress can be calculated.

$$\sigma_t = \frac{S}{A} = \frac{4 \cdot M_M (i_c - 1)}{\pi \cdot d^2 \cdot n} = \frac{4 \cdot 4{,}38e5 \cdot (7{,}2 - 1)}{\pi \cdot 28^2 \cdot 580} = 7{,}6 MPa$$

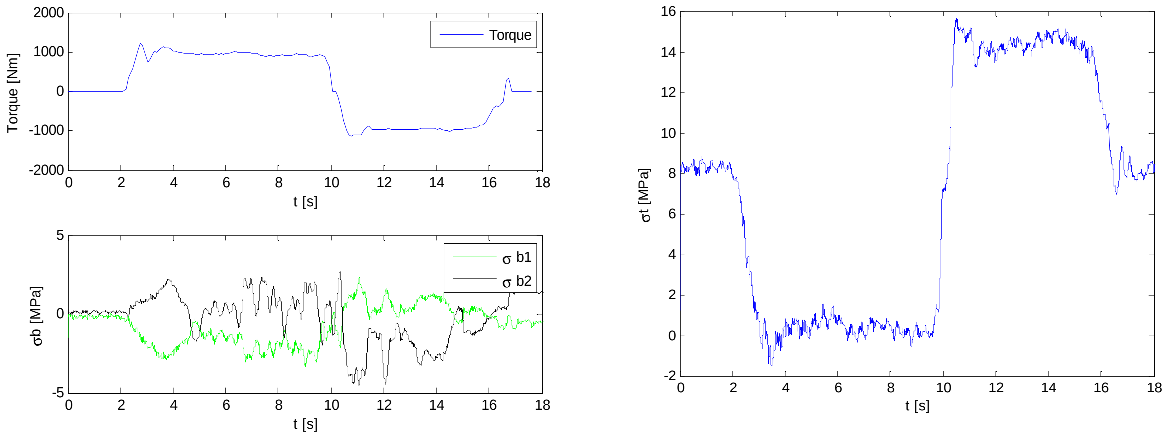


Fig. 5. Torque of two asynchronous motors and bending stress in two perpendicular planes (left) and tensile stress in the hinge (right) for the acceleration regime.

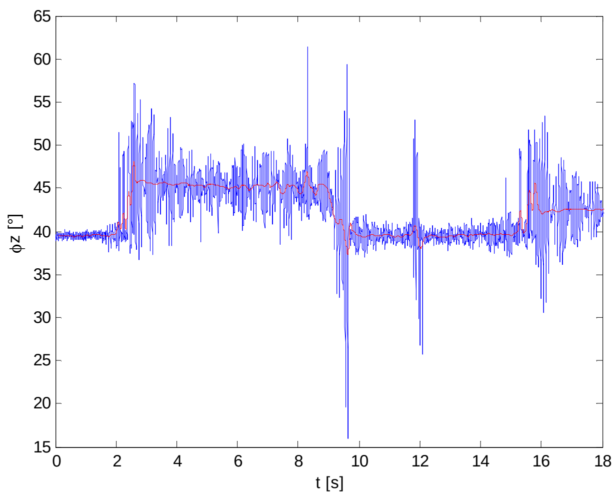


Fig. 6. Relative rotation of the gearbox to the asynchronous motor round the longitudinal axis.

Presented graphs proved the presence of the bend in the hinge. Measured tensile stress is in very good agreement with analytically calculated value. It can be seen that the tensile stress does not start at the zero point. This indicates that some stress remains in the hinge even in unloaded state. So it is necessary to evaluate only relative deviations of tensile stress. In Fig. 6 there is shown rotation of the gearbox round the longitudinal axis of the tram during the acceleration regime. For better transparency red line is added. It is a representation of mean value during the time. The average deviation of the angle ϕ_z during the acceleration (time about 2 s – 9 s) is 5°.

Results and Conclusion

The measurement proved the hypothesis that the gearbox hinge does not catch only tensile and pressure forces, vice versa it is also bending stressed. But the measured values of bending stress are quite low. This can be caused by low dynamic effect. The tested tram was empty and the quality of the rail track in the depot was quite good. Another reason could be that the gearbox hinge was mounted exactly with specified pretension so the rubber bedding is not so rigid and the hinge allows bigger movements. This hypothesis is proved by data measured by system Qualisys. Presented graph shows that movements are higher than admissible values for the claw coupling.

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