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FE ANALYSIS OF KNUCKLE JOINT PIN USEDIN TRACTOR TRAILER

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ABSTRACT

Tractor trailer is a useful equipment used in agriculture field for carrying heavy goods. To connect trailer to the tractor flexibly, a knuckle joint is used which consist of forks and a pin, a fork is attached to tractor rigidly and another fork is attached to the trailer by a pin. During acceleration of tractor, force acting on the joint is tensile and during deceleration it is compressive. Force acting over the joint is calculated by considering Newton's Second Law of motion. At the time of carrying heavy weights, due to its fluctuation a pin is subjected to high stresses. As the pin is a flexible element which can easily be replaced, it is considered separately for the analysis and finite element analysis is done on it.

Keywords: finite element analysis, knuckle joint, tractor-trailer, acceleration, deceleration.

INTRODUCTION

Tractor-trailer finds widespread use as a means of transportation in rural like agriculture field and in urban like goods transport as it is often cheaper. The effective design of any mechanical device or assembly demands the predictive knowledge of its behavior in working condition. It becomes a dire necessity for the designer to know the forces and stresses developed during its operation. This is also important from the view of selecting the right material. In recent years, the failure of assemblies due to stress accumulation has been a major concern for design engineers [1]. The analytical treatments of stress concentration can be traced back to 1900s [2]. Various experimental techniques have been developed over the years to calculate these localized stresses. However, it often becomes difficult to obtain these calculations either by mathematically or by experiments if the geometry is complex or requires significant resources to manufacture a prototype. Finite Element Method (FEM) has emerged as a viable option in this context. Over the years many a researchers have published numerous studies by using FEM.

Design of vehicles, especially effect of various operational loadings has been area of interest for many researches. The effect of such operational loads and hence the induced stresses was investigated FEA by Roslan Abd Rahman *et al*. [3].As it is used to carry heavy loads it is analyzed by some investigators partly, by considering different part of the assembly. Sufficient literatures on FE analysis of Chassis of trolley are available [4]. Another researcher did three dimensional finite element analyses of the chassis consist of a computer model or design that is stressed and analyzed for specific results [5]. The axle of trolley is also one of the important parts for critical failure modes [6]. Knuckle joint is designed and used in so many equipment for transmitting load. Some researchers have analyzed it as a part of steering mechanism of automobile for its weight reduction [7, 8]. Knuckle joint which is used in steering mechanism of racing car is also dealt and analyzed for optimization of weight, because weight is the important parameter that affects transmission efficiency of device [9]. Trailers used other than with tractor have been simulated and the stress analysis was performed. Another study show the use of models simulated in CATIA [10]. Koszalkaet *et al*. [11] used FEM to analyze the frame of a low loader truck. An iterative procedure has been used by Sane *et al*. [12] analyzing the developed stresses in a light commercial automobile.

Knuckle joint is a joint among two parts permitting movement in one plane only. It is atype of hinge joint. More often than not two parts of a machine are to be connected and restrained, for example two rods may be joined coaxially and when these rods are pulled apart they should not separate i.e. should not have relative motion and continue to transmit force. The paper presents a FE analysis for a pin used in the knuckle joint assembly of tractor trailers. The required solid model based on the real life application and dimension is modeled in ANSYS Workbench. The model is then discretized and meshed. Suitable constraints and load conditions are applied to it. The papers open with a short introduction on the use and need of stress analysis. Section 1 also contains a brief review of related literature. The problem is defined in section 2 followed by description of solid model in section 3. The obtained results are critically examined in section 4 and conclusions are drawn in the final section.

PROBLEM DEFINITION

Mass of trailer with weight placed on it alone is not responsible for the force acting over the knuckle joint. Rather acceleration with which tractor pulls trailer is responsible. Here a reference is taken in the current study from Newton's Second Law of Motion for the consideration. According to that a Force is equal to the mass of the body multiplied by the acceleration of the body.

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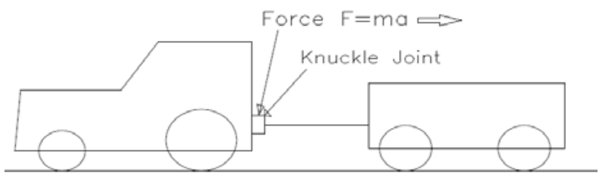

Figure-1. Block diagram showing direction of force during Acceleration.

When the tractor decelerates, direction of force becomes opposite to the direction shown in Figure-1. To calculate the force acting on the joint, a constant speed of 40 Km/hr i.e. 11.11 m/s is considered with time period of 5 minutes i.e. 300 Seconds during acceleration and 0.5 minute i.e. 30 seconds during deceleration. Trailer which is pulled by a tractor is having a mass 500 Kg when it is empty and 10000 Kg when it is full. According to Newton's Law of Motion, Force F= mass x Acceleration. And acceleration,

$a = \frac{\text{Final Velocity} - \text{Initial Velocity}}{\text{Time period}}$, $a = \frac{11.11 - 0}{300} = 0.037\ m/s^2$

Therefore, Tangential Force Acting on the joint, when the trailer is empty, F_1 = 500 x 0.037 = 18.57 N. Tangential Force Acting on the joint, when the trailer is full, F_2 = 10000 x 0.037 = 370 N. Due to braking or any other interruptions during the driving, the tractor get decelerate, which changes the direction and nature of tangential force from tensile to the compressive.

Deceleration, $a_1 = \frac{0 - 11.11}{30} = -0.37\ m/s^2$

The Tangential Force Acting on the joint, when the trailer is empty, during deceleration,F_3 = 500 x (- 0.37) = 185 N (Compressive). Tangential Force Acting on the joint, when the trailer is full, F_4 = 10000 x (-0.37) = 3700 N (Compressive). Similar to this sample calculation, forces has been calculated at different speed for acceleration as well as deceleration and for empty as well as full trailer.

Table-1. Tangential force during acceleration for empty trailer.

V(KMPH)	**V** (m/s)	**Acceleration** (m/s^2)	**Force** (N)
30	8.333333	0.027777	13.8888
40	11.11111	0.037037	18.51851
50	13.88889	0.046296	23.14814
60	16.66667	0.055555	27.77777

Table-2. Tangential force during deceleration for empty trailer.

V (KMPH)	**V** (m/s)	**Deceleration** (m/s^2)	**Force** (N)
30	8.333333	0.27777	138.8889
40	11.11111	0.3703	185.1852
50	13.88889	0.462962	231.4815
60	16.66667	0.555	277.7778

Table-3. Tangential force during acceleration for full trailer.

V (KMPH)	**V** (m/s)	**Deceleration** (m/s^2)	**Force** (N)
30	8.333333	0.02777	277.77777
40	11.11111	0.03703	370.3703
50	13.88889	0.0462	462.962
60	16.66667	0.05555	555.5555

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Table-4. Tangential force during deceleration for full trailer.

V (KMPH)	**V** (m/s)	**Deceleration** (m/s^2)	**Force** (N)
30	8.333	0.2777	2777.778
40	11.11	0.3703	3703.704
50	13.88889	0.46296	4629.63
60	16.66	0.55555	5555.556

MODELING OF KNUCKLE JOINT PIN

The first step in analyzing any machine assembly using FEM package is to draw a solid model. The solid model should incorporate all the complexities and features of the real life assembly. It is often seen in literature that the accuracy of obtained results from ANSYS are always directly dependent on the accuracy of the solid model to its physical form. In this case based on the dimensions actually measured for a trailer, a model has been prepared. Location of Forks and a pin is similar to as it is in actual case. The solid model is than imported into the FEM module and meshed using solid 186 elements.

As shown in Figure-2, boundary conditions have been given in processor stage of finite element analysis of knuckle pin. Material properties considered here are: Density=7850 kg/m^3, Young's Modulus E=2x10^{11} Pa, Poisson's ratio μ= 0.3, Bulk modulus G= 1.667x 10^{11}, Shear modulus υ = 7.69x10^{10}.

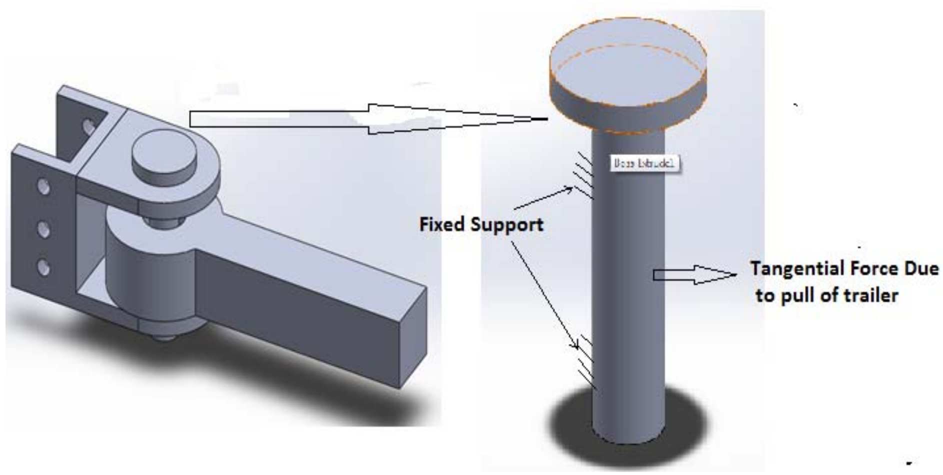

Figure-2. Knuckle joint assembly and pin.

RESULTS

The simulated problem is solved by using ANSYS workbench. Figure-3 shows the relation between the generated stress in the pin and the load intensity. In all the plots the stress monotonically increases with increase in load intensity. As can be predicated by simple mathematical calculation based on fundamental equations of mechanics forces generated during deceleration is in general more than acceleration. Hence the stress produced in deceleration phase is much higher than in acceleration. Figures 4-6 shows the simulated results for force 13.34 N, which is the case acceleration of empty trailer. The stress, strain and deformation plots for other cases are not shown to avoid redundancy of figures. The basic trend is similar in all the cases. The pin is connects the forks of tractor and the trailer. It behaves like a short column. A short column when compared with a long column is much stiffer. It simply means that it offers larger resistance to the applied force and hence a much larger force is needed to deform it. Figure-5 shows the total deformation the pin undergoes. Maximum deflection is seen at the midpoint. This is due to the fact that the pin is constrained (by the forks) in upper and lower position as shown by schematic in Figure-7.

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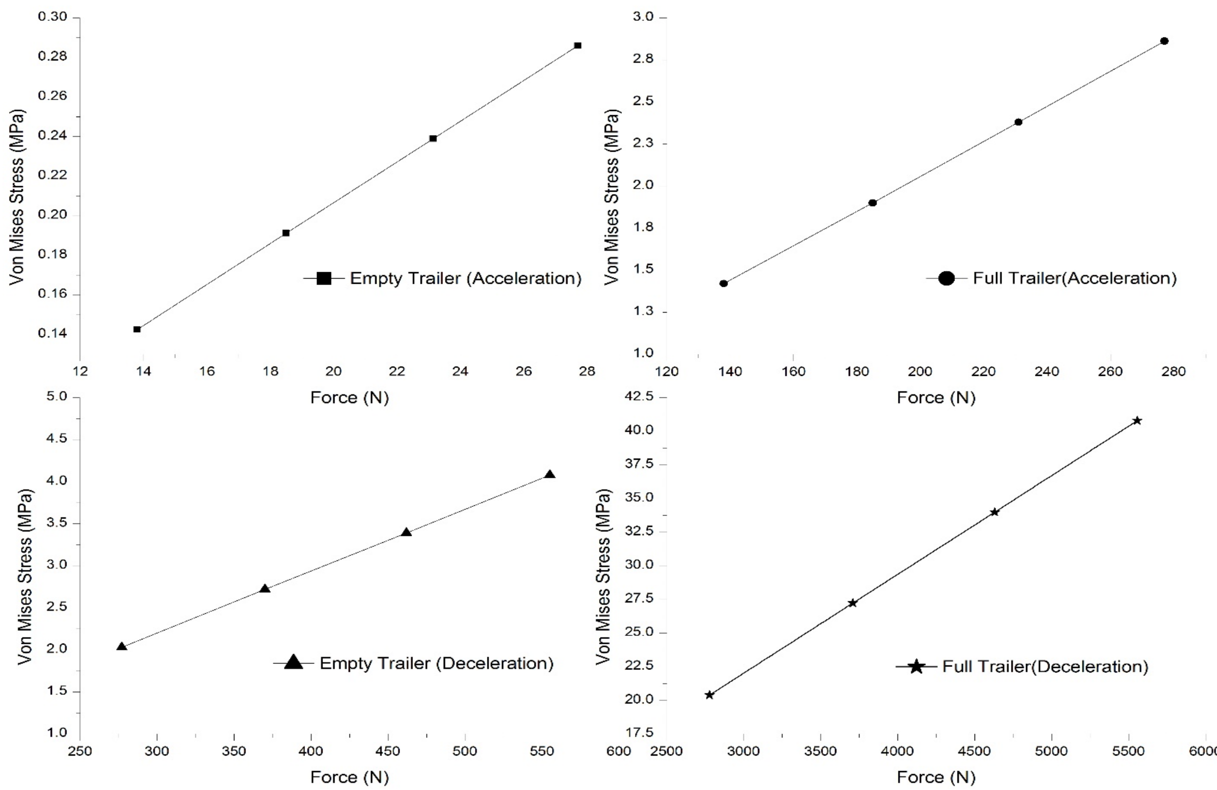

Figure-3. Von Misses stress vs. tangential forces.

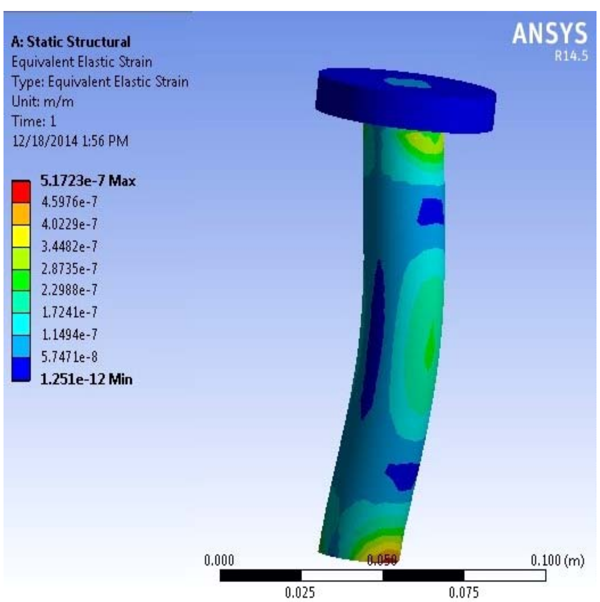

Figure-4. Typical equivalent strain generated.

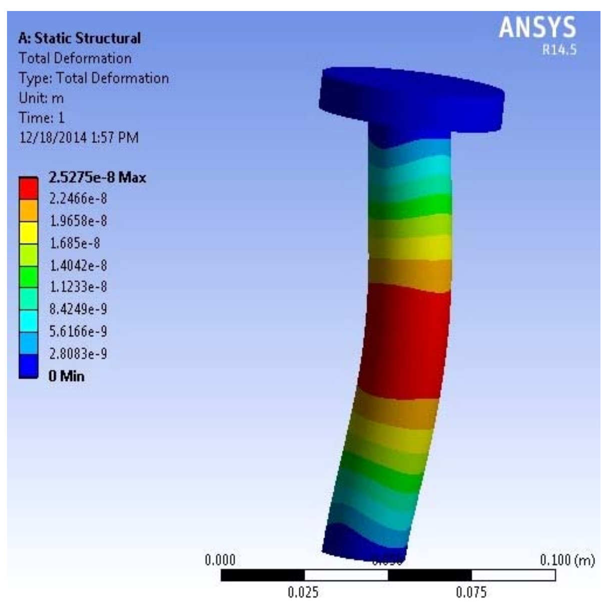

Figure-5. Total Deformation contour plot.

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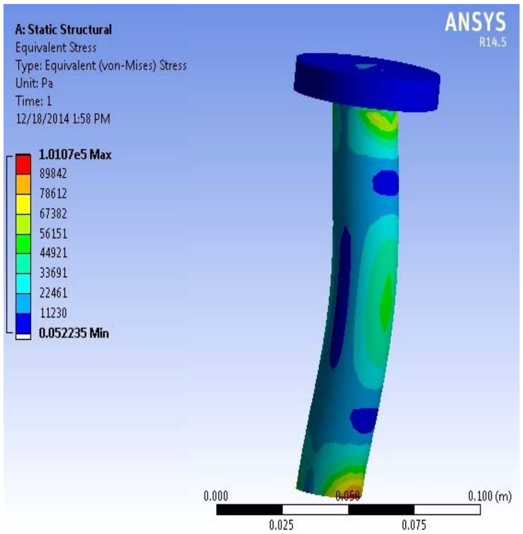

Figure-6. Von Mises Stress contour plot.

MATHEMATICAL VALIDATION OF RESULTS

Neglecting effect of mass we can treat the pin as a simply supported beam assuming that the tangential pulling force occurs at the centre of the pin (Figure-7).

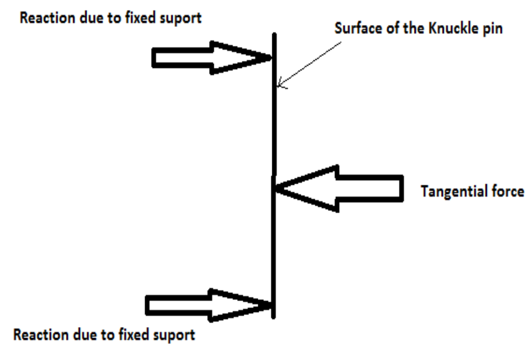

Figure-7. Graphical representation of reaction due to fixed support.

For the purpose of validation, consider Bending Equation as,

$$\frac{M}{I} = \frac{\sigma}{y}$$

For the case of 13.8 N tangential force, the Bending moment, M = 1.93 N-m, considering area moment of inertia (I) for the circular pin and the distance of its application (y) as d/2. Here diameter d is 0.02 m. After the calculation, σ = 1.562 N/m^2 which is much closer to ANSYS results.

Table-5. Validation of results for Acceleration when trailer is empty.

S. No.	Tangential force (N)	Von Misses stress (N/m^2)		% error
		ANSYS	Mathematically	
1	13.8	1.43E+05	1.51E+05	5.2
2	18.5	1.91E+05	2.01 E+05	4.9
3	23.14	2.39E+05	2.51 E+05	4.7
4	27.7	2.86E+05	2.98 E+05	4.02

Table-6. Validation of results for Acceleration when trailer is full.

S. No.	Tangential force (N)	Von Misses stress (N/m^2)		% error
		ANSYS	Mathematically	
1	138	1.42E+06	1.35 E+06	4.9
2	185	1.90E+06	2.05 E+06	7.3
3	231	2.38E+06	2.47 E+06	4.3
4	277	2.86E+06	2.98 E+06	4.02

Table-7. Validation of results for deceleration when trailer is empty.

S. No.	Tangential force (N)	Von Misses stress (N/m^2)		% error
		ANSYS	Mathematically	
1	277	2.03E+06	2.18 E+06	6.8
2	370	2.72E+06	2.59 E+06	4.7
3	462	3.39E+06	3.505 E+06	3.32
4	555	4.08E+06	4.26 E+06	4.25

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Table-8. Validation of results for deceleration when trailer is full.

S. No.	Tangential force (N)	Von Misses stress (N/m^2)		% error
		ANSYS	Mathematically	
1	2777.78	2.04E+07	2.18 E+07	6.42
2	3708.7	2.72E+07	2.805 E+07	3.03
3	4629.6	3.40E+07	3.57 E+07	4.7
4	5555.56	4.08E+07	4.29 E+07	4.86

CONCLUSIONS

After studying knuckle joint used in tractor-trailer and analysis a pin for Von Misses stresses the following conclusions can be drawn:

- Knuckle joint is the most preferable joint in commercial field to join a shaft which is axial having no eccentricity.
- Knuckle pin is the flexible element of the joint, which can be remove to disconnect trailer from tractor.
- Numerical value of tangential force acting on the knuckle joint is maximum in case of deceleration at the same speed of the tractor.
- Obviously as tangential force increases the Von misses stresses increase, their intensity is maximum in case of deceleration.
- Conditions may become worst in case deceleration of a trailer full of load.

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