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Computer Aided Lifting Hook Modeling and Stress Analysis

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Abctract

Lifting hook is one of the important components used in materials handling systems for safely transporting and lifting the loads. In this study, 3D modelling of a lifting hook that has 40 kN lifting capacity specified in DIN 15400 and DIN 15401 standards and stress analyses of lifting hook model by using boundary conditions have been performed. Critical points have been determined based on stress analysis results. After critical points are determined curved beam theory is used to calculate stresses on critical points of lifting hook. An illustrative example has been given to compare the stress results obtained by curved beam theory and finite element simulations.

Keywords: CAD, Curved beam theory, Stress analysis, Lifting hook

Bilgisayar Destekli Yük Kancası Modellenmesi ve Gerilme Analizi

Öz

Yük kancaları, yüklerin taşınması ve güvenli bir yük transportu için taşıma sistemlerinde kullanılan önemli parçalardan biridir. Bu çalışmada, DIN 15400 ve DIN 15401 standartlarında tanımlanan, 40 kN kapasiteli bir yük kancasının üç boyutlu modellenmesi ve sınır koşulları uygulanarak yük kancasının gerilme analizi yapılmıştır. Gerilme analizi sonuçlarına dayanarak kritik noktalar belirlendikten sonra yük kancası üzerindeki kritik noktalardaki gerilmeler eğri eksenli çubuk teorisi kullanılarak hesaplanmıştır. Sonlu elemanlar simulasyonu ve eğri eksenli çubuk teorisi kullanılarak elde edilen gerilmelerin karşılaştırılabilmesi için açıklayıcı bir örnek sunulmuştur.

Anahtar Kelimeler: BDT, Eğri eksenli çubuk teorisi, Gerilme analizi, Yük kancası

1. Introduction

The lifting of goods generally occurs on construction sites, in factories or other industrial plant. Lifting appliances include chain sling, rope sling, ring, link, hook, plate clamp, shackle, swivel or eyebolt (OSHC, 2002). Lifting hook which is one of the lifting components is selected according to lifted loads, load collectives, mean running time per day in hour related to one year. There has been great deal of interest to exhibit stress distribution along curved and shank sections of lifting hook. İmrak et al. (2005) investigated simple hook with 50 kN lifting capacity in order to compare the stress results obtained by approximate and Timoshenko methods. Simple hook with 05 number was used. Fetvacı et al. (2006) used IDEAS software to model simple hook with 08 number and exact solution technique was employed to compare stress results. Krishnaveni et al. (2015) employed different hook cross sections which are trapezoidal, circular and T-shaped to compare simulation results. Uddanwadiker (2011) conducted finite element analysis and photo-elasticity validation of hook. Devaraj (2015) modelled a crane hook with different material and performed stress analysis using Ansys Workbench. Onur (2017) exhibited that how stresses imposed upon lifting hook at different sling angles and sizes and what was the safety factor of lifting hook related to sling type, size and angle. In this study, computer aided lifting hook modelling has been performed by means of SolidWorks and imported by ANSYS Workbench. Finite element simulation of hook model is done in order to reveal critical points where maximum stresses occur. Based on simulation results curved beam theory is applied to calculate stress values occurred on critical points.

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2. Investigated Lifting Hook

Lifting hook has been selected by using DIN 15400 (1990) and DIN 15401 (1983) standards. Strength classes which are M, P, S, T and V are specified in DIN 15400 related to proof stress values. Steel to be used for lifting hook is selected according to hook type and strength class. Hooks are used together with drive group. Drive group is selected considering dimensions of loads, mean running time per day in hour related to one year in DIN 15020 (1974) standard. Lifting hook is then selected related to strength class, drive group and lifting capacity. In this study, crane or any other handling system that can carry 40 kN is considered in lifting hook selection. Strength class P is selected where minimum requirement for upper yield strength is 315 MPa. Hook material is selected as StE 355 considering regulations. Mechanical properties of StE 355 steel have been shown in Table 1.

Table 1. StE 355 steel mechanical properties

Density	7850 kg/m^3
Young's Modulus	200000 MPa
Yield Strength at tension and compression	400 MPa
Poisson Ratio	0.3
Tensile Ultimate Strength	600 MPa

It is assumed that lifting hook run with 2m drive group. DIN 15400 defines lifting hook type with numbers. Hook number 2.5 is selected regarding above assumptions. Technical drawing and dimensions of hook no. 2.5 have been shown in Figure 1 and Table 2.

Table 2. Dimensions of type GS single hook

Single hook No.	Parameters (units in mm)		
2.5	a_1	a_2	a_3
	63	50	72
	b_1	b_2	d_1
	53	45	42
	e_1	e_2	h_1
	152	167	67
	h_2	l_1	r_1
	58	253	7
	r_2	r_3	r_4
	10	65	132
	r_5	r_6	r_7
	132	90	78
	r_9	d_2	d_3
	134	36	M36
	d_4	l_2	m
	30	83	32
	n	r_9	r_{10}
	10	2	10
	r_{11}		
	3		

Drop forged with threaded shank without nose (GS) single hook type is selected. As seen from detail E, m is thread length. It is screwing length between nut and threaded shank. DIN15400 stipulates that screw type shown in detail E shall be metric M36 threads.

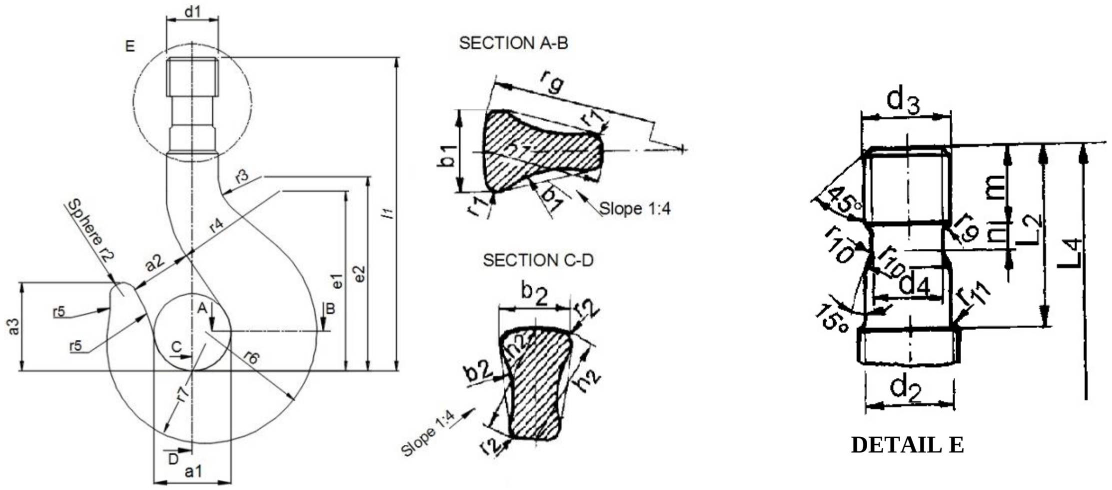
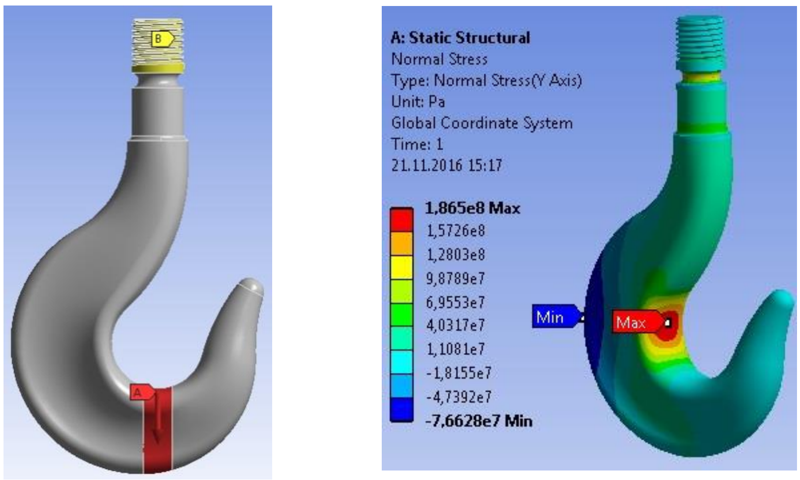


Figure 1. Technical drawing of hook no. 2.

3. Lifting Hook Stress Analysis

Stress analysis has been performed by ANSYS Workbench where hook model is imported from Solidworks. In order to perform finite element simulation boundary conditions are applied to the hook model. Since there is not any displacement between nut threads and hook shank treads, displacements in x, y and z directions are assumed to be zero. Maximum lifting capacity of investigated hook which is 40 kN has been applied to load carrying surfaces of hook where lifting hooks are to be in contact with fittings as shown in Figure 2(a). Tetrahedron elements are used as finite element and 5 mm mesh size is selected. Stress contour on lifting hook investigated has been shown in Figure 2(b).



(a) (b)

Figure 2. (a) Boundary conditions (b) Stress contour on lifting hook.

Maximum and minimum stresses occurred at points A and B indicated in Figure 1 as 186.5 MPa and -76.628 MPa respectively. Based on critical point locations, stresses occurred on points A and B have been calculated by curved beam theory.

4. Curved Beam Theory

Neutral axis and the centroidal axis of a curved beam, unlike the axes of a straight beam, are not coincident and also that the stress does not vary linearly from the neutral axis. The notation is defined as follows:

(Budynas and Nisbett, 2006) where r0 is radius of outer fiber (mm), ri is radius of inner fiber (mm), h is depth of section (mm) c0 is distance from neutral axis to outer fiber (mm), ci is distance from neutral axis to inner fiber (mm), rn is radius of neutral axis (mm), rc is radius of centroidal axis (mm), e = distance from centroidal axis to neutral axis (mm), M is bending moment (Nmm), A is cross-sectional area (mm2). Section A-B of hook no. 2.5 in Figure 1 is assumed to be approximate trapezoidal cross section to facilitate curved beam theory calculations. rn for trapezoidal cross section of curved beam is given by the equation (1) (Budynas and Nisbett (2006)).

$$r_n = \frac{A}{b_0 - b_i + \left[(b_i r_0 - b_0 r_i)/h\right]\ln(\frac{r_0}{r_i})} \quad (1)$$

Applied load which is 40 kN causes axial stress and bending stress in trapezoidal cross-section which sum of stresses occurred on critical point A and B are as follows:

$$\sigma_A = \frac{Q}{A} + \frac{M c_i}{A e r_i} \quad (2)$$

$$\sigma_B = \frac{Q}{A} - \frac{M c_0}{A e r_0} \quad (3)$$

where b0 is width which is located far away to centre of curvature of trapezoidal cross section (mm), bi is width which is located close to centre of curvature of trapezoidal cross section (mm), Q is 40 kN. Maximum and minimum stress results at points A and B obtained by using curved beam theory have been shown in Table 3.

Table 3. Curved beam theory solutions.

Point	A(mm^2)	M (Nmm)	c_i (mm)	c_0 (mm)	e (mm)	r_i (mm)	r_0 (mm)	Stress (MPa)
A	2471.1759	2,374922.10^6	23.045	-	5.978	31.50	-	σ_A= 133.492
B	2471.1759	2,374922.10^6	-	46.195	5.978	-	100.74	σ_B=-57.841

5. Results and Discussion

In this study, lifting hook which has 40 kN lifting capacity has been modelled and stress analyses have been performed. Critical points where maximum and minimum stresses occur have been determined. Stress analysis results and theoretical results obtained by using curved beam theory have been shown in Table 4. Results indicate that maximum and minimum stresses occurred at points A and B as 186.5 MPa and -76.628 MPa respectively in finite element analysis. Maximum and minimum stresses occurred at points A and B as 133.492 MPa and -57.841 MPa respectively in curved beam theory calculations. It is seen from Table 4 that maximum stress result found by using FEA on A point is 1.39 times greater than maximum stress result found by curved beam theory. In addition, minimum stress result found by using FEA on B point is 1.32 times greater than maximum stress result found by curved beam theory. İmrak et al. (2005) found that there is 1.56 times difference between exact and approximate stress solutions on investigated lifting hook with 5 number. Fetvacı et al. (2006) investigated a lifting hook with 08 number which has 50 kN capacity and found that maximum stress value occurred by using finite element analysis was 65.22 MPa. Krishnaveni et al. (2015) investigated a lifting hook which has 60 kN capacity and found that maximum stress value occurred by using finite element analysis was 177.71 MPa for trapezoidal cross section. DIN 15400 proposed that maximum stress is 160 MPa and minimum stress is -63 MPa when exact method is used for investigated lifting hook type. There is a good harmony between maximum and minimum stress results obtained by this study and regulation. Author aimed to investigate a specific lifting hook which has different type (numbered as 2.5 in regulations), different material and different lifting capacity than lifting hooks investigated in the literature. Safety factor of hook investigated is determined by using Ansys Workbench. Safety factor has been determined to be 2.14 under maximum lifting capacity. Finite element analysis is a good way to assess reliability of lifting hooks since material properties such as modulus of elasticity and poisson's ratio are also considered in the analysis.

Table 4. Maximum and minimum normal stress values at points A and B.

Point	σ_{max} (FEA) (MPa)	σ_{max} (Curved beam theory) (MPa)	σ_{min} (FEA) (MPa)	σ_{min} (Curved beam theory) (MPa)
A	186.50	133.492	-	-
B	-	-	-76.628	-57.841

6. Conclusions

In this study, lifting hook with 40 kN lifting capacity is modelled and stress analysis is made by using Ansys Workbench. Curved beam theory is employed to calculate theoretical maximum and minimum stress values occurred on lifting hook investigated. Safety factor of investigated lifting hook when lifting hook is subjected to maximum lifting capacity is determined. Results indicate that maximum and minimum stresses occurred at points A and B as 186.5 MPa and -76.628 MPa respectively in finite element analysis. Maximum and minimum stresses occurred at points A and B as 133.492 MPa and -57.841 MPa respectively in curved beam theory calculations. Safety factor has been determined to be 2.14 under maximum lifting capacity.

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