The Pulley Grooves Wear Interpret Analytical form Based on the Hertz Contact Theory and Finite Element Analysis

Zhu Qing & Shuisha Ling
School of Mechanical Engineering
Shanghai University of Engineering Science
Shanghai, 201600
China

Abstract

Using mechanics basic theory, the Hertz contact theory and finite element analysis ANSYS, the aim is to study the contact problem of wire rope and pulley, and establish the contact model of wire rope and pulley. The theory and simulation result are effective to explain the wear of pulley groove. According to the analysis results from the design and use of pulley, putting forward some measures on how to avoid pulley wear and wear indentation after processing method, which can effectively extend the service life of the pulley, as well as provide certain theoretical support for the pulley processing technology.

Keywords: Hertz theory; Pulley groove wear contacts; Finite element analysis

Introduction

In recent decades, the heavy machinery research teams in China has carried on the research breakthrough to the crane key technology, so that our crane products have achieved remarkable results, and continues to the large-scale, intelligent development, and the pulley as an important part of the crane equipment, widely used in aviation, water conservancy project, chemical engineering, metallurgy and other engineering industries. During the crane's long-term operation, There are obvious indentation and wear in the bottom of the crane pulley groove. Taiyuan iron and steel plant expansion project in July 2006 investment casting crane production, in August 2008 found a large casting crane pulley deformation, wear serious. The 36 with type pulley has four rim grinding through, the other pulley have varying degrees of wear such as shown in Figure 1, which brings some technical problems to the enterprise. The contact wear problem between wire rope and pulley was studied in the world. Pu Han Jun [1] in his doctoral dissertation by the contact analysis of nonrotating wire rope and pulley, the contact model of the wire rope and the pulley is deduced, and the external contact stress and wear of the wire rope and the pulley are analyzed theoretically, the internal friction wear model of the nonrotating wire rope was established.

Li Xi , Cao Shi-Hao and other [2] through hertz and finite element analysis software ANSYS,A study on the contact fatigue of the rail wheel with the surface of the rail is carried out, under different axle load and operating conditions, obtained the crack tip stress intensity factor of the different position. Liao Hong-Wei [3]—the influence of on the fatigue damage of wire ropes was studied by means of the various pulley of the rope groove hardness from HB170-HRC60， finally the sensitivity index of the fatigue life of the wire ropes was introduced. Chen Hai-Rong[4]—The initial research on the pulley of the port crane in 60t, obtained the stress distribution and the maximum contact stress of the surface of the wire rope groove. GuHai-Tao, Gao Chong-Ren[5] of wire rope force characteristic of and spectral coefficients by the crane load level and load and considering the wire rope of the reverse bending and other factors, and gives the improving measures to the fatigue life of the steel wire rope pulley. Tao Yan, Sun Shu -Cheng [6] the best matching measure of the lifting mechanism and wire rope for hoisting mechanism is presented. Jiang [7-8] and nawrocki[9] analyzing and calculating the finite element model of wire rope strands. The results are in agreement with the theoretical analysis of Costello and some experimental results. At present, although the domestic and international scholars have done a lot of research on the wear of wire rope and pulley, it is still in the preliminary stage of study.

In this paper, combining the mechanics theory and Hertz theory, analyzed the different hoisting heavy wire rope and pulley rope groove of the contact stress, and established the wire rope and pulley contact model, and by the finite element analysis, and ultimately come to different hoisting heavy lower pulley rope groove of the stress distribution and the stress nephogram, and put forward some prevention measures, which can provide certain academic support for the pulley groove machining process, even provides effectively prolong the service life of the pulley.

Fig 1: Pulley Wear Diagram

1. Establish Contact Model Rope and Pulley

Wire rope is a kind of flexible space helicoid. Rope and pulley during operation, because the rope to withstand the load is variable load, rope pulley groove surface will wear at work for some time, to solve this problem, first assume that the rope and the rope groove sidewall contact with interference does not occur on the pulley rope groove contact stress analysis.

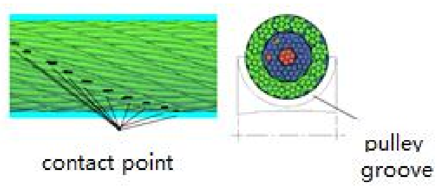

Fig 2: Rope and Pulley Groove Contacting Schematic Diagram

Figure 2 shows a typical class 18x7 non-rotating wire rope and pulley wheel groove contact with most companies use schematic figure, after straightening the bent wire rope, mark the outside real point of contact within the rope on one strand. Friction and wear rope and development takes place on a real point of contact in the wheel groove. If rotating wire rope and pulley contact section of length L; outside flank side yarn twist pitch of P_g in stocks; rope outside Shares will be made by the N_w root, root side per share have N_s wire; rope pulley has eaten into the depth of the rope half the diameter. It can be deduced rope groove in contact with the wheel as the number of points N_{mw}:

$$N_{mw} = \frac{LN_W N_s}{2\sin\beta_w P_g} \quad (1)$$

According to the geometry relationship, the length of the contact section of wire rope and pulley groove L=(D +d)θ/2

θ -the pulley rope wrap angle in radians;
d/ D- the diameter of the rope and pulley,

The rope groove in contact with the wheel point number can also be written as

$$N_{mw} = \frac{(D+d)\theta N_W N_s}{4\sin\beta_w P_g} \quad (2)$$

1.1 Contact Load Analysis from the Rope and Pulley Groove of the Hoisting System

In Fig3, according to Taiyuan Heavy Industries 250t rope pulley winding system diagram, analysis shows that the spreader on both sides of the rope pulley in the same condition is substantially equal to the force, so just study the forces of a pulley. Thus simplifying the rope and pulley contact with the forces.

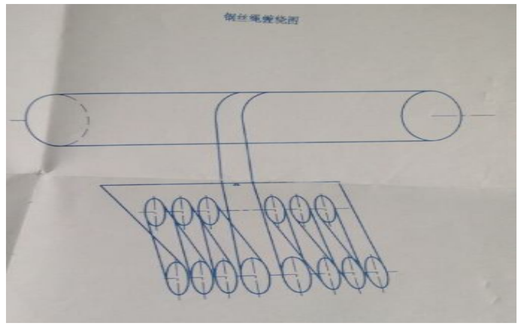

Fig 3: Rope and Pulley Winding Diagram

Acting on the rope pulley groove, assuming the pulley rope wrap angle is θ, obtained under micro-element model for the roleof rope.As shown in Figure 3.

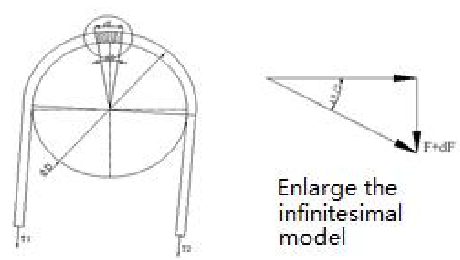

Fig 4: Rope and Pulley Groove contact with Loaded Infinitesimal Model

Rope and pulley contact process will produce relatively pulley sliding, stress analysis can be obtained through the vertical equilibrium equation:

$$F\sin\frac{d\theta}{2} + (F + dF)\sin\frac{d\theta}{2} - dF_N = 0 \quad (3)$$

dF_N—micro segment rope positive pressure，dF—Rally increment is infinitesimal on approximately equal role in infinitesimal friction on the rope；Because dθ is very small, equivalent to$\frac{d\theta}{2} \approx \sin\frac{d\theta}{2}$，Because the wire ropeof the large overhead crane main lifting system is run slower rope when the working operation, and therefore the centrifugal force is negligible, the above equation simplifies to:

$$Fd\theta + dF\frac{d\theta}{2} - dF_N = 0$$

Ignore higher order terms: $dF\frac{d\theta}{2}$，the above equation simplifies to:

$$Fd\theta - dF_N = 0$$

And because$dF = \mu dF_N$, Joint formula obtained：$\mu d\theta = \frac{dF}{F}$，Integration on both sides can get pulley contact surface radian contact positive pressure:

$$q(\theta) = F_1 e^{\mu(\theta-\theta_2)} \quad (4)$$

From (2), (4), obtained rope grooves each contact point normal average pressure.F_{W-N}

$$F_{W-N} = 4\sin\beta_W P_g \frac{F_1 e^{\mu(\theta-\theta_2)}}{(D+d)\theta N_W N_s} \quad (5)$$

μ—the coefficient of friction rope and pulley rope groove in contact with the rope pulley adopted here at 0.11 coefficient of friction lubrication conditions. According to the formula can be drawn positive pressure rope and pulley contact surface distribution. As shown in Figure 5.

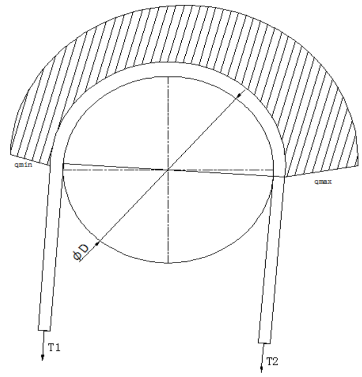

Fig 5: Rope and Pulley Groove Positive Pressure Contact Surface Distribution diagram

From Figure 5 positive pressure rope and pulley rope groove surface wrap angle decreases gradually decreased, and the maximum force rope pulley occurs in the beginning of the rope and pulley contact points, the theoretical analysis derived from the rope force formula indicates the wrap angle$\theta = 180^{\circ}$.that is to ignore the impact of the rope deflection, the force rope ismaximized.

1.2 Hertz Contact Analysis Theory Establish Rope Pulley Rope Grooves

The contact between the rope and the pulley rope grooves may be considered an object contacts the contact between the two surfaces, wire rope and rope groove stocks between the points of contact with a lot of power when it is not loaded, and after loading the elastic deformation of the material, the contact point into the contact surface, these features can be used on the classical Hertz theory, it is assumed that the two elastic rope and pulley cylinder, two elastic body contact surfaces in the role of the force of an oval face, the maximum contact pressure occurs in elliptical surface q_{max} center[10]。

$$q_{\max} = \frac{3p}{2\pi ab} \quad (6)$$

P—The force of the rope pulley rope grooves;
a—Elliptical contact surface semimajor axis;
b—Elliptical contact surface semiminor;

Elliptical contact surface of the long and short axle by the following formula

$$\begin{cases} a = m^3\sqrt{\dfrac{3(1-v^2)p}{2E(A+B)}} \\ b = \dfrac{n}{m}a \end{cases} \quad (7)$$

m, n—Contact stress coefficient between the rope and the rope grooves calculated according to Hertz theory;
E—Elastic modulus pulley;
V—Poisson's ratio pulley;

Coefficients A, B by the equation (8) is obtained.

$$\begin{cases} A + B = \frac{1}{2}\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) \\ B - A = \frac{1}{2}\left(\frac{1}{R_1} - \frac{1}{R_2} - \frac{1}{R_3}\right) \end{cases} \quad (8)$$

R_1—The radius of the wire rope side strands;
R_2——Radius pulley groove;
R_3——Radius pulley;

According to Hertz theory know pulley rope groove when under load rope and the rope grooves each contact point can be considered oval spots, Taiyuan Heavy Industry hoist normally used to 250t, 200t, 150t load on the main hoisting pulley, from (5), (7), (8) can be obtained at each point of contact in contact with the pulley rope calculation the normal contact pressure, as shown below

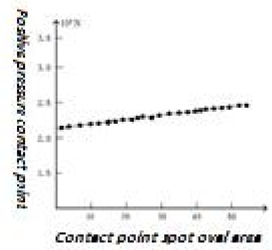

Fig 6: 250t between the Pulley Groove and Side Strand Wire Rope Each Contact Point Normal to Positive Pressure

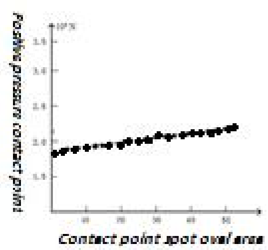

Fig 7: 200t between the Pulley Groove and Side Strand Wire Rope Each Contact Point Normal to Positive Pressure

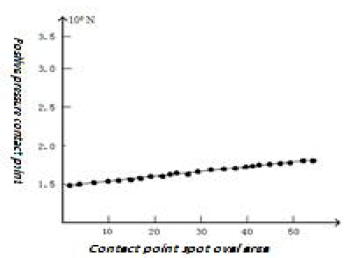

Fig8150t between the pulley groove and side strand wire rope each contact point normal to positive pressure

As can be seen in Figure 6, 7, 8, with the increase in weight lifting, pressure and contact patch area rope pulley groove of contact points are significantly increased, weight lifting 250t, 200t, 150t peak contact pressure 2.49x10 ^6N , 2.25x10 ^ 6N, 1.87x10 ^ 6N. When we can see the rope and pulley rope groove effect maximum positive pressure occurs in the rope and pulley rope groove geometric center.

2. Finite Element Rope and Pulley Contact Point Analysis and Preventive Measures

The steel actual exposure and use finite element software ANSYS its rope grooves - pulley contact stress finite element analysis. In order to obtain a high accuracy, and not too large computational grid mesh wire when the contact surface and the wheel groove whichever is less, and the non-contact surface of the mesh rope grooves desirability larger value, just rope groove contact pressure peaks corresponding contact points limited analysis, as shown below.

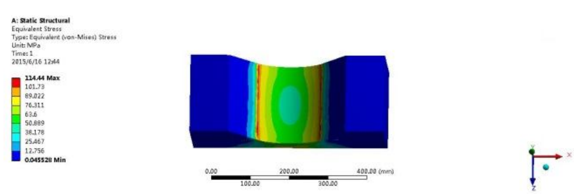

Fig 9: Contact Stress Distribution 250t Pulley Groove

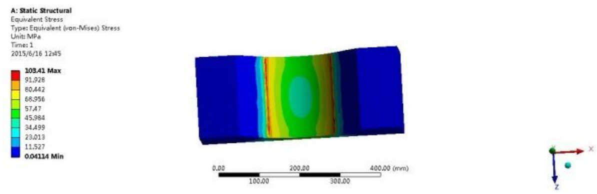

Fig 10: Contact Stress Distribution 200t Pulley Groove

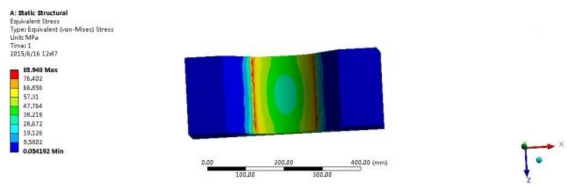

Fig 11: Contact Stress Distribution 150t Pulley Groove

From Figure 9,10,11 can be drawn wire rope hoist 250t, 200t and 150t maximum value stress distribution pulley groove contact area, contact stress were 114.44MPa, 103.41MPa and 85.948MPa. Stress analysis can be explained by an effective Figure 1 Actual pulley wear problems, in line with long-term job pulley wear process status. Pulley groove wear side is mainly due to heavy wear and tear after the initial roll-forming pulleys, pulley bottom geometric center and geometric center of the web eccentric, or pulley bottom portion of the thickness of the main force of a deviation, and pulley installation, the weaker side of the rim just the rope attached to the inclined angle of the side, after the horizontal component pulley Loaded produce tiny plastic deformation leads to the rim, with the increase in working hours, the plastic deformation increases, the geometric center of the bottom pulley removal the geometric center of the webs, the relative trajectory of the bottom rope and pulley becomes oval, rope and pulleys sliding motion into even roll wear gradually increased. Eventually lead rope and rim wear, fast damage, and along the bottom of the rim and the webs transition joints wear out.

The following measures should be taken to prevent creasing in the design and use of stage wear.

1. Strict prosecution bottom pulley and a web geometric center line, forming the bottom end surface of the pulley irregularities error no larger than 1mm.
2. Pulley rope along the bottom center of the center of the web 30o direction should be equal to the rim thickness t1 or t2 t1-t21mm, high rope center wing thickness t3 = t4 or t3-t41mm.
3. Forged wheels, the bottom part properly thickened, or rolling pulley bottom portion of the thickened, and strictly control the end surface flatness errors. May be considered if necessary trough hardening, to improve abrasion resistance.
4. Recommend heavy into the factory pulley strict checks and controls t1, t2, t3, t4 thickness and bottom center and the webs center deviation t5, and save inspection records。
5. Recommend that users regularly check and found that the timely replacement of wear serious.
6. With suitable oil (or fat), regularly lubricate wire rope.
7. When purchasing a new cord should pay attention to the consistency with the original rope and rope replacement structure type and brand to be careful.
8. In the main working condition of the crane should avoid excessive shock and point operations.

3. Conclusion

Pulley under different loads occur wear for the study, through the analysis of the mechanical rope and pulley, the establishment of a formula calculation model with rope pulley contact pressure and the side strands of steel rope and pulley groove of contact points, the use of hertz theory draw each point contact method positive pressure to the method of calculating the results of the contact point positive pressure profile using finite analysis of the stress distribution pulley, effectively explains pulley wear patterns, and proposed some measures to prevent wear and tear of the pulley, which will prolong the life of the pulleys to provide some theoretical guidance.

References

Pu Han-Jun Non-rotating wire rope hoist Theoretical research and the use of life estimate [D] Guangzhou: South China University of Technology; 2012.

Cao Shi-Hao, Li XI, Zhang Si-Fang. Differences of Hertz theory and finite element analysis wheel contact fatigue [J] Mechanical Engineering, 2015, 51 (6): 126-134

Liao Hong-Wei Fatigue Behavior and Damage Mechanism of rope [D]. Hubei：Wuhan University of Technology; 2006

Chen Hai-RongSECT-61T-8113-type container crane main lifting pulley wear failure research [D]. Shanghai：East China University of Science and Technology; 2011

GuHai-Tao, Gao Chong-Re, Liang Chen. Rope strength properties and bending fatigue life analysis [J] Mechanical Engineering and Automation, 2013 (5): 122-124

Yan Tao, Sun Shu-Cheng Wang Jun-Tong. Lifting machinery from matching pulley and rope hoisting mechanism [J] China Science and Technology Information, 2011 (18): 94-95[7] W. G. Jiang，J. L. Henshall，J. M. Walton. A concise finite element model for three-layered straight wire rope strand [J]. International Journal of Mechanical Sciences.2000, 42: 63-86.

W. G. Jiang，M. S. Yao，J. M. Walton. A concise finite element model for simple straight wire rope strand [J]. International Journal of Mechanical Sciences.1999, 41(2): 1999.

Anne. Nawrocki, Michel. Labrosse. A finite element model for simple straight wire rope strand [J]. Computers & Structures. 2000, 77(4): 345-359.

[10]Yan Bing-Shan, Wang Qi-Chang. Rail and rail damage mechanics [M] Chengdu: Southwest Jiaotong University Press, 2012