# Structural Design and Analysis of the Truss Manipulator

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**Abstract: In the process of engine assembly, many parts have heavy mass and large volume, such as fan bracket assembly and so on. Manual handling and installation is time-consuming and inefficient; the traditional truss handling manipulator occupies a large space, high cost and inconvenient operation. In order to solve the above problems, aiming at the fan tray assembly, this paper puts forward a kind of truss power manipulator, which can grasp and carry the fan tray assembly of different sizes, and has the advantages of simple structure, convenient operation and low cost. It has high economy and high efficiency, and has high practical application value.**

**Keywords: Engine Assembly; Truss; Booster Manipulator; Structural Design**

## 1. Introduction

"Made in China 2025", after decades of rapid development, our country has become the world's first manufacturing power, at present, China's economic development stage transformation, industrialization has entered the late stage, our country industrial categories, has a certain industrial system and manufacturing capacity, have the basic conditions of the construction of industrial power. However, we are still in the process of industrialization, and compared with the advanced countries in the world, our gap is still very large [1]. In the context of China's transition from a manufacturing power to a manufacturing power, it is necessary for us to realize semi-automation and automation of manufacturing industry, and use intelligent equipment to replace or assist artificial work [1~2].

At present, the material handling robot is widely used in industrial production, although its operation ability is strong, but there are some problems in the accuracy, production efficiency and other aspects [2]. Most of the existing mobile robots are large in size and act fast. In the limited working space such as assembly lines, there are limited movement and safety problems [3~4].

In view of the above problems, in this paper, a fan bracket assembly has designed a truss power manipulator, which can assist workers in handling materials. It has simple structure, small space occupation, convenient operation and low cost, and can play the advantages of labor and equipment at the same time, improve security and improve work efficiency, and reduce the cost of enterprise [5].

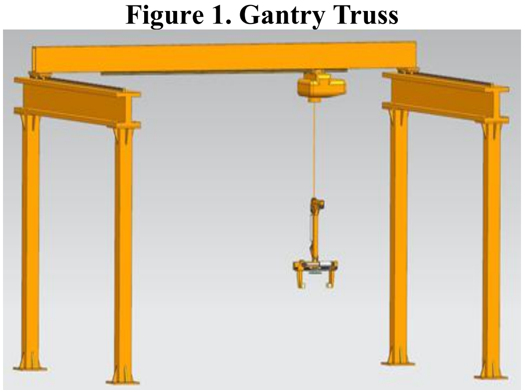
## 2. Scheme Design

Process of installing the fan bracket assembly for the final assembly line. Workers need to move the material from the material area to the engine transmission line for assembly. Different fan bracket assembly sizes are also of different sizes. After measurement, the max

ng to the handling object, the structure of the manipulator adopts the claw type, which can be achieved by the push of the cylinder, and the claw clip and release. The fan bracket assembly is mounted on the front of the engine, so it needs to be flipped so that the manipulator can grab the parts to flip it in place for installation.

The gantry truss designed in this paper mainly realizes the function of moving the manipulator in the X-Y axis space, ensuring the flexibility of the space movement of the assisted manipulator. The Z-axis movement is completed by the crane, with simple structure and cost saving. The rationality of the true structure is verified by designing the structure and mechanically analyzing the key parts of the truss power manipulator. As shown in Figure 1.

**Figure 1. Gantry Truss**

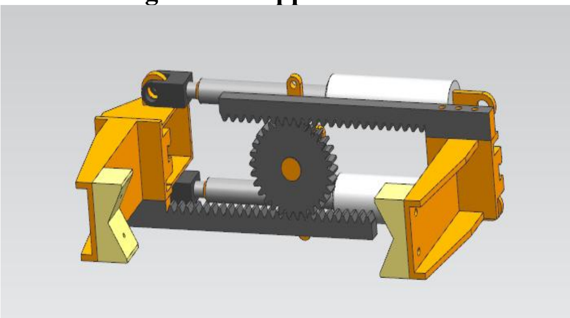


## 3. Architectural Design

### 3.1 Grasping structure design

In order to meet the size of the fan bracket assembly, the grasping part of the manipulator adopts the clip, as shown in Figure 2, the fan bracket pulley installation to carry the fan bracket. The left and right mechanical grip through the cylinder push and gear rack drive to achieve the grip grasp and release.

**Figure 2. Gripper Structure**

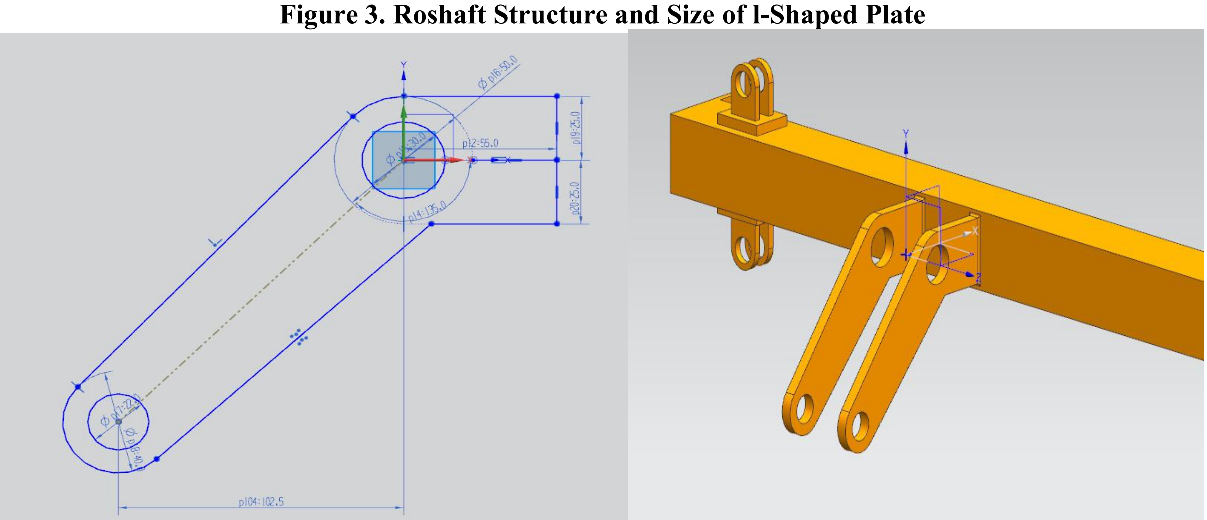


Cylinder selection calculation: the grasping mass of the manipulator is 50 kg, the maximum stroke of the fan bracket is determined by the fan clamp is 80 mm, and the contact part of the front grip and the workpiece needs soft contact to prevent the breakage of the workpiece, so the polyurethane material is used. The fan bracket so the surface is rough, the friction coefficient between polyurethane and the workpiece is f=0.6, the area is 5000 mm2, according to the conditions, the working pressure of the clamp is about 0.086 MPa, so the Japanese SMC cylinder, the model is CG1BN50-100Z, the stroke is 100 mm, the minimum use pressure is 0.05 MPa, the maximum use pressure is 1.0 MPa, can be used normally.

### 3.2 Flip Structure Design

The fan bracket is mounted on the front of the engine after grasping from the part frame. Therefore, it is necessary to design a flip structure to flip the fan bracket through the cylinder push. The flipped structure is shown in Figure 3. In order to meet the above work requirements, it is necessary to design the structure of the rotating shaft part, and through the L-shaped structure, the grip part can be pushed by the cylinder. By analysis, the L-shaped plate has an angle of 135. According to the size of the middle support bracket and the approximate size of the cylinder, the projection distance between the two rotating parts is 102.5 mm.

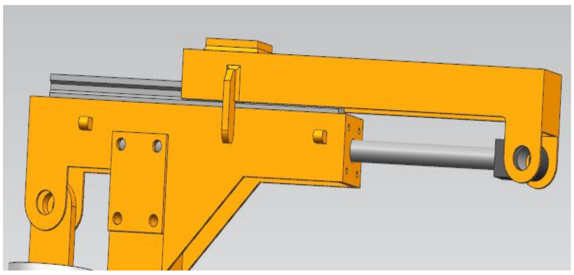
**Figure 3. Roshaft Structure and Size of l-Shaped Plate**



Cylinder selection calculation: analyze the torque of cylinder pushrod thrust and gravity of the workpiece, $F\times L_1 = Mg \times L_2$ can calculate F=1587.1 N. $F = P \times A$ Available, working pressure P=0.37 MPa. Therefore, the Japanese SMC cylinder is CG1BN80-200Z, 200 mm, the minimum service pressure is 0.05 MPa and the maximum service pressure is 1.0 MPa, which can be used normally.

After the mechanical grip grasps the fan carrier and turns it over, the center of gravity will move forward due to the large mass of the fan carrier. In order to ensure the stability of the structure, we need to ensure that the overall structure is vertical. The cylinder push rod and slide can be passed at the upper end, so that the center of gravity is located in the middle part of the structure, to ensure that the structure is vertical. The structure is shown in Figure 4

**Figure 4. The Cylinder Push Rod and Slide Structure**



### 3.3 Design of the Gantry Truss Structure

The function of the gantry is mainly to realize the space movement of the manipulator to meet the movement in the X-Y direction. The design of the gantry should follow the three principles of smooth movement, simple movement process and easy operation and stroke meets the requirements. If the travel of gantry needs to meet the range of working space, the travel of the Y axis of gantry should be greater than 5.8m and the X axis of gantry should be greater than 3.8m. The gantry adopts square plate counterwelding structure and all welding parts need to be stress treated, which can effectively prevent deformation. All four feet are fixed on the ground with anchor bolts to ensure the rigid connection.

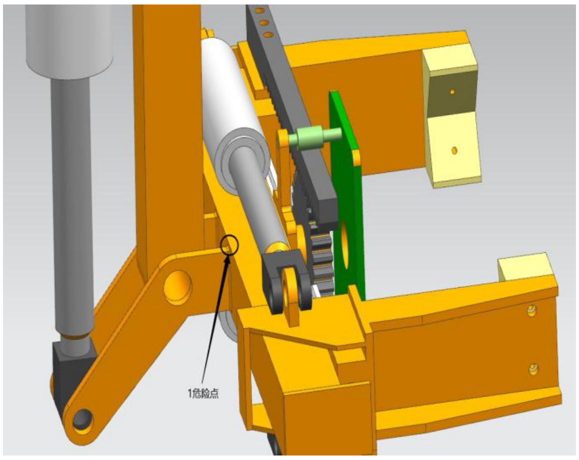
The truss slide adopts roller guide rail, which has the characteristics of fast transmission speed, low noise, easy installation and maintenance, and long life, so the X-Y axis sliding structure of the gantry truss chooses BWC-V roller guide rail, through the rolling contact between the roller and the guide rail, to meet the straight reciprocating movement of the load platform. The inner structure of the roller adopts the double-column angular contact bearing structure to meet the requirements of the dynamic load conditions.

## 4. Analysis and Selection and Calculation of Key Components

### 4.1 Flip Mechanism Strength Check

After the booster manipulator grabs the fan bracket and reverses it, the structure is shown in Figure 5. In the sharp change of the shape of the object will produce stress concentration, stress concentration will lead to the local increase of stress, so in the stress concentration position, it is generally the dangerous point of the parts. Based on the previous experience and preliminary analysis, the dangerous point of the flipped structure is shown in Figure 1. Analysis and judging the dangerous points can provide a reference for the following check.

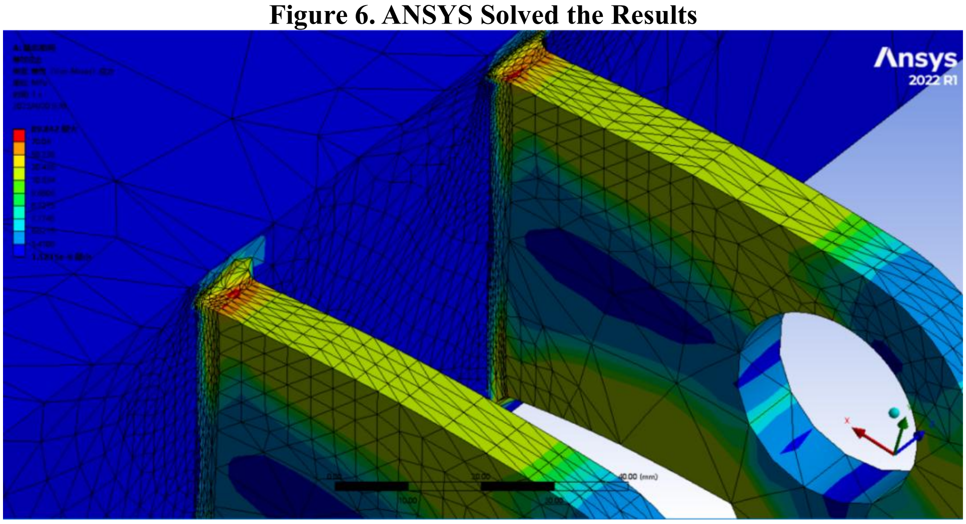
**Figure 5. Flip the Structure and Its Dangerous Points**




The mass of the fan bracket is taken at 50kg. Mg is the resultant force of the fan bracket and grip gravity, and F1 is the thrust generated by the cylinder. The equivalent moment produced by F1 and Mg should be in the opposite direction M1=M2. F1=1706.6 N. If 1 point in the figure is the danger point, the equivalent moment at 1 point is M = 148.225 Nm.

The above data were substituted into ANSYS software for analysis. The results of ANSYS software are shown in Figure 6. The maximum stress point analyzed by the software is in the same position as the danger point judged before, from which the results are effective. From the stress cloud diagram, the maximum stress value is σ Max=89.8 MPa.

**Figure 6. ANSYS Solved the Results**




The L-shaped plate and the gripper addition need to be welded together, and their working strength is not very high. Therefore, to choose the steel with good comprehensive mechanical properties and good welding properties, Q345 ordinary carbon structural steel should be selected as the material.

Q345 low alloy steel belongs to the plastic material, which can be checked by the third strength theory.

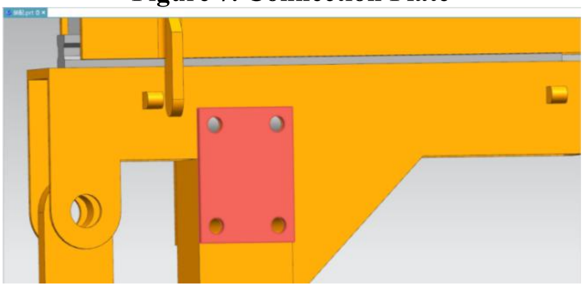
The third strength theoretical formula: $\sigma_1$-$\sigma_3$≤[σ],[σ] Allow-use stress

According consulting the mechanical design manual, the yield limit of Q345 steel is 345 MPa, and the safety factor is S=1.1. Therefore, the allowable stress [σ] =313.6 MPa, σ Max=89.8 MPa <[σ]. In conclusion, the structural strength here meets the use requirements and is safe.

### 4.2 Check the Strength of the Connecting Plate Bolts

As shown in Figure 7, the middle bracket and the small cylinder bracket are connected together through the connecting plate. In order to ensure the fastening and safety, the connecting bolts.

**Figure 7. Connection Plate**



According to the force of the connecting plate bolt, the bolt is mainly affected by the transverse load F, when the bolt is subjected to the shear force generated by the load. Therefore, it is necessary to calculate whether the bolt will fail under the shear force. The bolt shear force is calculated as: $\tau=\frac{Fs}{m\frac{\pi}{4}d^2}\leq\tau_p$. allowable shear stress of the bolt at static load $\tau_p=\sigma_p/2.5$. Load stress of bolts $\sigma_p=\frac{\varepsilon K_t K_u \sigma_{-1t}}{K_\sigma S_a}$. The parameters in the formula are selected according to the mechanical design manual.

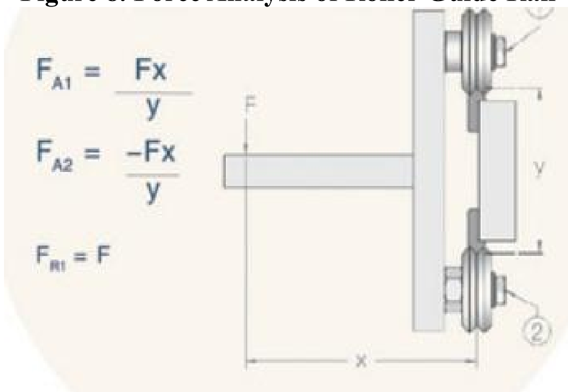
The nominal diameter of the initial selected bolt is D=10 mm. Suitable parameters are selected according to the mechanical design manual, $\varepsilon = 1$; $K_t$ =1 ; $K_u$ =1.5 ; $\sigma_{-1t}$ =230 MPa; substitution formula: allowable stress $\sigma_p=\frac{1\times1\times1.5\times230}{3.9\times3.5}$ =25.3 MPa, allowable shear stress $\tau_p$=10.1 MPa. The tangential load of the bolt is 70 Kg, then $F_s$=343 N. Apply the load to the shear stress formula: $\tau=\frac{343}{1\times\frac{\pi}{4}\times0.01^2}=4.367$ MPa < τ. The shear force generated by the load is less than the allowable shear stress, so the bolt strength with a nominal diameter of 10mm meets the requirements and can be used.

### 4.3 Selection and Calculation of Truss Slide

The X-Y axis sliding structure of the gantry truss selects the BWC-V roller guide rail of Zhixin Hang Hardware and Electromechanical Co., LTD. After downloading and consulting the technical manual, the size of the guide rail and roller shall be selected.

The selection of roller guide rail should consider the installation mode first. The radial load capacity of roller guide rail is greater than the axial load capacity, so the radial medial installation is adopted. The total load of the roller rail is 300 Kg, the load is F=1470 N, and the radial force of the roller is $F_{R1}$=F/2=735 N; According to the Fig.8 force analysis diagram, the axial force of the roller is $F_{A1}$=1470×10/150×2=49 N， $F_{A2}$=-49 N.

**Figure 8. Force Analysis of Roller Guide Rail**




According to the axial and radial forces of the roller and the working environment, consult the product manual and choose the ordinary roller (carbon steel). The roller series is W-and the adaptive specification is 1. After the roller is selected, the installation center distance shall be determined. The calculation formula of the center distance of the inner installation is A=B + X, where B is the width of the installation base. X shows X 21 roller = 22.20 mm. Enter the formula for the available installation center distance A=172.2 mm.

Life calculation:

(1) From the previous calculation, the radial force of the roller is $F_R$ = F/2 = 735 N; the axial force of the roller is $F_{A1}$ = 1470×10/150×2 = 49 N， $F_{A2}$ = -49 N

(2) The load coefficient LF of the largest bearing roller is calculated. The calculation formula is $L_F=\frac{F_A}{F_{A_{max}}}+\frac{F_R}{F_{R_{max}}}$. FA represents the axial force bearing the largest roller, $F_{A_{max}}$represents the rated axial load capacity of the roller, $F_R$ represents the radial force bearing the largest roller, and $F_R$ indicates the rated radial load capacity of the roller. The results are available into the formula, $L_F$= 0.797 < 1, the load coefficient is less than 1, to meet the requirements.

(3) To estimate the life of the roller, the calculation

formula is, life $=\left[\frac{L_c}{(L_F)^3}\right]$, where $L_c$ represents the life constant, $L_F$ represents the load coefficient, $A_F$ represents the correction coefficient; refer to the product technical manual, we know the life constant of W1 type $L_c$ =55 Km, the calibration coefficient $A_F$= 0.9 can calculate the estimated life of the roller is: life = 99 Km.

## 5. Conclusion

In this paper studies the production situation and work content of the engine assembly line, designs a kind of truss manipulator for the engine fan bracket assembly, and carries out the overall structure design, strength check, simulation analysis and selection calculation. Through the analysis and calculation results, prove that the design scheme is reasonable, can meet the work needs, effectively improve the production efficiency and product quality, save the production space.

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