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Design of Steel Plate Grasping Vacuum Equipment on TruLaser 3030 with Servo Motor

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Abstract. A vacuum gripper is a device that uses a vacuum cup as a suction device and holds the workpiece load so that the workpiece can go through the process of moving from one position to another. In this research, the gripping vacuum is the main tool in the sheet metal material transfer machine so that the material can be easily moved from the wooden pallet to the TruLaser 3030 fiber machine table. The process of making this machine design requires careful calculation of the formula so that the appropriate machine components are obtained to lift material loads. The components needed in the design of this machine include a gripper vacuum, servo motor, load-bearing shaft, transmission drive, gear transmission, and a steel frame using a 300 x 300 Wide Flange Beam as a support for the whole machine. The sheet metal material used as the load is SS400 material sheet metal with a thickness of 15 mm and an area dimension of 2.44 m x 1.22 m. For this reason, strong components are needed and can withstand vertical and horizontal loads from the movement of materials and the load of the sheet metal material itself. It is recommended to use a suction motor on a gripping vacuum with a suction power of 48 m3/hour and electric power of 1.3 kW. In addition, the servo motor used must be able to withstand a load of 350 kg with a design power of 171.7 watts and a torque of 93 Nm, and straight gears with a ratio of 4:3.

Keyword: Servo Motor, Sheet Metal, Straight Gears, Vacuum Grippers.

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1 Introduction

Today's growing industry requires a variety of automated work systems where the need to use human labor is beginning to be limited. In addition to being an obstacle in social problems, this is also one of the obstacles in application in the industrial zone itself. Industry requires an innovative and creative machine that does not need to involve many humans but can increase a work on machine productivity. One solution to this problem is the retrofit process. The retrofit

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process is the process of replacing or adding a component to the machine with the aim of adding value to the performance of the machine [1-3].

Servo motors are electrical devices used in smart industrial machines. This machine serves to push or rotate objects with high precision control in terms of angle position, acceleration and speed, an ability that ordinary motors do not have [4-6]. In previous studies, experiments have been conducted on servo motors to analyze the required torque value and rotary willingness of the motor against CNC wood lathe machines. By referring to the initial power of the servo motor, this condition is required to find a power plan to improve the required servo motor capability. Power plan is sought using a correction factor of 1 because the known power of the servo motor specification is the maximum power so the calculation does not require a correction factor [7-9].

Based on the research, it can be concluded a problem, what if the servo motor that is able to operate automatically is intended to carry the load of the steel plate using a gripping vacuum as a gripper on the steel plate. Although the load that can be used is limited, servo motors can be operated with the help of gears and shafts so as to increase the power and power needed to lift loads that are more than the ability of the motor. But it needs a more thorough calculation so that the gears and shafts are able to lift the desired load in the design of the steel plate materal moving machine model so that it can operate properly.

2 Methods

2.1 Field Data Retrieval

The field data collected first is the actual weight of the steel plate to be used as a bound variable in the steel plate transport machine on the TruLaser 3030 L49 Fiber machine. Then searched the surface area data that the machine will place according to the actual circumstances in the field. After obtaining the field data, data is then searched through calculations about the strength of the load-bearing shaft, straight gear transmission, servo motor power, and frame strength.

2.2 Equations

Some of the equations used in this study include. Calculate the suction force required by the vacuum to lift the load of the steel plate by using the following formula,

$$Vertical\ suction\ force\ \ (F_s) = \left(\frac{m}{\mu}\right) \times (g + a) \times S \qquad (1)$$

In equation 1 above, m is the mass of the workpiece, μ is the coefficient of friction for steel 0.5, g is the acceleration of gravity, a is the acceleration of the motion of the workpiece, and S is a safety factor with a minimum value of 1.5.

In addition to vacuum suction force, it takes servo motor plan power to determine the strength of the shaft to be used with the following formula

$$Motor\ plan\ power\ (P_d) = f_c\ .P \tag{2}$$

where, f_c is the corrective factor of the motor and P is the power obtained from calculating potential energy with the time of functioning of the energy in the workpiece. In addition to motor power, the torque caused to the shaft is also a state that must be considered and becomes an important factor in the determination of the shaft in the following formula.

$$Shaft\ torque\ (T) = 9.74\ x\ 10^5\ \times \frac{P}{n_2} \tag{3}$$

where, n_2 states the rotation speed of the shaft obtained from calculating the frequency of servo motors is 50 Hz with 4 poles. After that, the permission sliding voltage is required to assess the middle of the shaft because of the shear load that occurs due to the rotation of its axis with the formula

$$Permission\ sliding\ voltage\ (\tau_a) = \frac{\sigma_B}{sf_1\ .\ sf_2} \tag{4}$$

where, the value σ_B is the tensile strength of the material that can be taken in the table, and the value of sf as a voltage correction factor [10-11]. The formula of the clearance and torque sliding voltage on the shaft can be determined the diameter of the shaft used with the formula

$$Shaft\ diameter\ (D_S) = \sqrt[3]{\frac{5{,}1 \times K_t \times C_b \times T}{\tau_a}} \tag{5}$$

where, K_t is a correction factor from the twist moment and C_b is a correction factor due to the bending load suffered by the shaft later.

Next calculate the specifications and capabilities of gears with carbon steel material for the construction of the S 45 C machine with the following formula

$$Tangential\ Force\ (F_{t1}) = \frac{102 \times P_d}{v_1} \tag{6}$$

where, P_d is the power plan for the servo motor so that it is possible for the gear transmission to adjust the power, and v_1 is the roving speed of each gear. The use of unlucky tangent force will later be involved in the calculation paired with the bending load with the formula

$$Bending\ load\ (F_{b1}) = \sigma_A \times m \times Y_1 \times fv_1 \tag{7}$$

where, σ_A is the permitted bending voltage accordingly in the table, m is the mass of the steel plate, Y_1 is the gear shape factor, and fv_1 is the dynamic factor according to the shaft rotary speed table. Tangential forces and bending loads are combined to see the thickness of the gears needed in the transmission system so as to be able to support the load according to the formula

$$width\ of\ gear\ (b) = \frac{F_{t1}}{F_{b1}} \tag{8}$$

where, this calculation requires one side of the gear, because the gears are paired and collide with the same width so as not to occur unilateral loading.

Furthermore, the strength of the frame with a total load of 1 ton so that it is known the strength of the frame to meet the steel load permit limit according to the formula

$$Steel\ voltage\ (s) = \omega \times \frac{N}{A} \tag{9}$$

where, ω is the bending factor according to the table [10-11], N is the vertical normal load for frame loading and with the frame load itself, and A as the cross-sectional area of the Wide Flange Beam frame 300 x 300 according to the Wide Flange Beam table.

2.3 Calculation

A. Calculation of Suction Motor Power Needs

The suction power of the vacuum motor is determined from the calculation of the vertical load that the vacuum receives from the material especially the steel plate. This can be calculated by using formula (1) as the basis for determining the load. The loading that occurs affects the magnitude of the vacuum motor's power and the length of its duration of use. The heavier and longer the use, it takes a suction motor that has a larger capacity so that it is able to support the weight of the workpiece. As for the vacuum cup model used, it can be determined from the type of material to be transported. Of course there is a difference between the load of cardboard material and steel plates of the same mass. This can be seen from the specifications of the suction motor manufacturer so that it can be determined easily the specifications and types needed to build the construction of the machine.

B. Calculation of Axis Specification Requirement

Shaft specifications can be determined through the calculation process so that the corresponding shaft diameter is determined using the formula (5). Determination of shaft diameter through the formula, can be supported by calculating the torque that occurs on the shaft (3) and the shear voltage allowed to occur on the shaft (4). The calculation of these formulas involves many machine construction tables so that accuracy and table reading skills are needed.

C. Calculation of Straight Gear Specification Requirements

Straight gear transmission is known as a frequent transmission and is commonly used in engine construction. This is due to the ability of straight teeth that are able to lift large loads and the process of working is fairly simple from other types of gears. For that straight gears have a simpler calculation of formulas with good material resistance. To find the gear specification can be calculated by the formula of the gear in general and especially the width of the gear in the formula (8). The width of the tooth is related to the tangential force formula (6) and the bending load formula (7) so that table instructions are needed in order to know the permissible bending load value for jis standard S 45 C machine construction carbon steel material.

D. Calculation of Servo Motor Power Requirements

The power of the servo motor is seen from the strength and power requirement to lift the load of steel plate material with a mass of 350 kg for maximum loading. First, the torque requirement must be determined to produce a rotation of the shaft transporting the load and transmitted to the servo motor. In this case it will make it easier to calculate because the torque used will be directly proportional and transferred by the gear transmission to the servo motor. After that, the servo motor can be determined according to the servo motor manufacturer's catalog so that the selection of this component is more in accordance with the existing servo motor. For the calculation of the required power servo motor can be used formula (2).

E. Calculation of Skeletal Strength Needs

In this process, the frame size used is Wide Flange Beam 300 x 300 to maximize the strength of the frame in supporting excess loads. The feasibility of the frame used in a construction can be calculated using equation (9) to determine the voltage of the steel. After the steel is determined the amount of voltage produced, then the value is compared to the steel clearance voltage (1600 kg/cm^3) with the material Fe 360 or equivalent to SS 400 through the bending factor table for the steel frame.

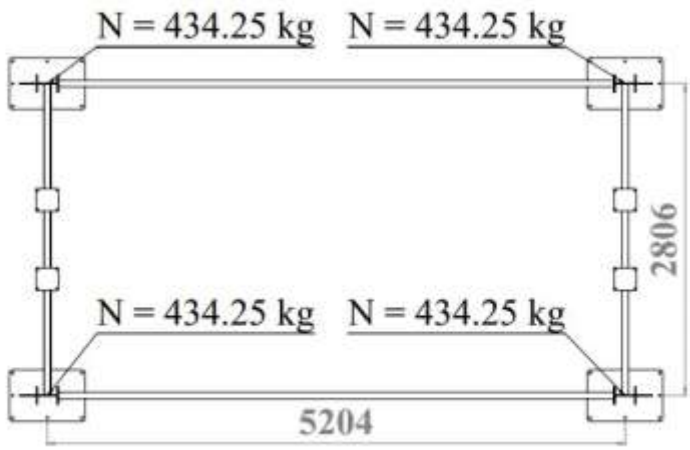

Figure 1. Design (top view) of machine construction frame planning

3 Result and Discussion

3.1 Failure Modes Analysis and Effect Analysis (FMEA)

Here is the field data that has been collected into its own data related to the actual thickness of the material used and the calculation of the mass of steel plates with the formula of the mass of the steel type: *Workpiece material is sheet metal carbon* (SS400). Material dimensions: 2.44 m x 1.22 m. Actual material thickness: 11.8 mm, 11.9 mm, 12.0 mm, 14.0 mm, 13.9 mm, 14.0 mm, 14.8 mm, 15.0 mm, and 15.0 mm. The acceleration of the plate towards the top is 1.5 m/s^2.

3.2 Failure Modes Analysis and Effect Analysis (FMEA)

Failure Modes and Effect Analysis (FMEA) analysis serves to provide weighting at severity (S), Occurance (O) & Detection (D) values based on the potential effects of failure, causes of failure & RPN (Risk Priority Number) value in the event of increased down time TruLaser 3030 L49 Fiber machine. The weighting figures used in the Failure Modes and Effect Analysis (FMEA) analysis are obtained from the results of observations and discussions with related parties, including Maintenance & Engineering, Production.

Based on data from the Failure Modes and Effect Analysis (FMEA) analysis obtained the value of RPN (Risk Priority Number) from the largest value to the smallest value, so that the Failure Modes and Effect Analysis (FMEA) analysis which has the largest RPN (Risk Priority Number) value is that the machine system does not run perfectly. Based on the results of the RPN (Risk Priority Number) & the results of the analysis of ailure Modes and Effect Analysis (FMEA), the results of the largest RPN (Risk Priority Number) value, then improvements were made with the aim of reducing or avoiding the occurrence of increasing down time TruLaser 3030 L49 Fiber machine repeatedly.

Table 1. Proposed Improvements

Potensial Cause & Failure	Potential Causative Factors Cause & Failure	Proposed Improvements
Irregular material loading process	The material loading process still uses a manual process, namely with human power assisted by forklift tools. This is a major obstacle in the material loading process because the tool is limited and dangerous for the health and safety of machine operators when continuously lifting using human power.	Make modifications to the system by adding a transporting machine and load mover. This modification is done by designing a machine design that is able to transport steel plate materials so that it makes it easier for operators to work.

Based on Table 1 obtained the proposal of improvements resulting from the results of RPN (Risk Priority Number) & the results of the analysis of failure Modes and Effect Analysis (FMEA). 5W +1H Analysis Table on the proposed improvement of potential cause & failure in the form of irregular material loading processes, so that the following results are obtained.

Table 2. 5W+1H Analysis Of Irregular Material Loading Process Improvement Proposals

WHAT	WHY	WHERE	WHEN	WHO	HOW
What is the repair plan?	Why do you need to make repairs?	Where are these repairs made?	When was the repair done?	Who becomes a PIC in repair?	How do I make those repairs?
Engine modification by adding a load-carrying machine	To prevent increased down time for future processes	Repairs are made in the material loading area on the machine table	Repairs are made In the material loading area on the machine table	Engineering Division boss	Modifications are made by adding a load-carrying machine that is able to grip while moving steel plate material from the wooden pallet to the machine table.

TruLaser 3030 L49 Fiber machine is a cutting machine with a laser beam cut eye that is able to penetrate the SS400 steel plate up to a thickness of 15 mm. The ability of this machine is not only limited to plates, but also all materials made of steel plates such as hollow pipes, UNP steel, round pipes, and so on. Cutting results that are considered better than cutting using plasma cutting are one of the options why laser machines are used in the steel plate industry.

The results of the RPN (Risk Priority Number) analysis and the results of the Failure Modes and Effect Analysis are the priority is the irregular material loading process. The proposed improvement plan is to create a separate tool capable of lifting loads and at the same time moving them so that the time needed for the material loading process is faster and provides safety and work comfort to machine operators. In addition, tools can also increase work productivity for employees so that fast and easy work time can support future production. Human power efficiency can also be done and make more human labor allocated to the more needy parts. The addition of the tool is carried out by designing the machine using vacuum gripper components, servo motors, and wide Flange Beam 300 x 300 range as the main components in the engine design.

3.3 Calculation and Analysis of Vacuum Gripper Needs

In the calculation of force in the handheld theory for vertical strength in the vacuum grasp used variables bound to the acceleration of plate motion a = 1.5 m/s^2 and the cross-sectional area of the material A = 2.98 m^2. The motion acceleration variable is made with this value because it sees the help of a large plate and requires slow movement, therefore accelerated with that value. As for the cross-section area is determined from the standard area of existing materials, which is 2.44 m x 1.22 m = 2.98 m^2. For the free variables used, the material with a thickness of 12 mm, 14 mm and 15 mm follows each using 3 samples as a comparison. The results of measuring and calculating the mass of a material with the formula m=p x l x t x 7850 kg/m^3 in determining the actual mass of the material are as follows:

Table 3. Results of Calculating the Mass and Vertical Force of the Vacuum

Sample	Actual Thickness of Material (h actual) (mm)	Material Mass (m) (kg)	Weight On Vertical Suppression Theory (Fs) (kg)	Pressure Intensity In Cup (p) (kg/mm^2)	Pressure Intensity In Each Cup @8 pcs (p) (kg/mm^2)
Formula	Measurement	Measurement	Fs = (m/μ)(g+a)S	p = Fs/A	p' = p/8
1	11.8	275.7	9354.5	3139.1	392.4
2	11.9	278.1	9435.9	3166.4	395.8
3	12.0	280.0	9500.4	3188.1	39.5
4	14.0	326.6	11081.5	3718.6	464.8
5	*3.9	324.8	11020.5	3698.2	462.3
6	14.0	326.6	11081.5	3718.6	464.8
7	14.8	345.8	11733.0	3938.6	492.3
8	15.0	350.0	11875.5	4241.3	530.2
9	15.0	350.0	11875.5	4241.3	530.2

3.4 Pivot Counting

Using formulas (2), (3), (4) and (5) the calculation of the needs of important components required by machine construction begins with calculating the power of the plan for the system.

$$Plan\ power\ (P_d) = f_c \,.\, P$$
$$Plan\ power\ (P_d) = 1.0 \times 171.7$$
$$Plan\ power\ (P_d) = 171.7\ \text{watt}$$

Furthermore, it takes the torque that occurs on the shaft to see the loading ability.

$$Torque\ that\ occurs\ in\ the\ shaft\ (T) = 9.74 \times 10^5 \times \frac{P}{n_2}$$
$$Torque\ that\ occurs\ in\ the\ shaft\ \ (T) = 9.74 \times 10^5 \times \frac{171.7}{1500}$$
$$Torque\ that\ occurs\ in\ the\ shaft\ \ (T) = 111490.5\ \text{kg.mm}$$

Then calculated the sliding voltage of the permit on the shaft to see the voltage on the shaft.

$$Permission\ sliding\ voltage\ (\tau_a) = \frac{\sigma_B}{sf_1\,.\,sf_2}$$
$$Permission\ sliding\ voltage\ (\tau_a) = \frac{58}{6.0\ x\ 2.0}$$
$$Permission\ sliding\ voltage\ (\tau_a) = 4.83\ \text{kg/mm}^2$$

After obtaining the result of the torque that occurs on the shaft and the permit sliding voltage on the shaft, it is known the diameter of the shaft needed for the loading of steel plate material.

$$Shaft\ Diameter\ (D_s) = \sqrt[3]{\frac{5{,}1 \times K_t \times C_b \times T}{\tau_a}}$$

$$Shaft\ Diameter\ (D_s) = \sqrt[3]{\frac{5{,}1 \times 1.0 \times 2.0 \times 111490.5}{4.83}}$$

$$Shaft\ Diameter\ (D_s) = 61.75\ \text{mm} = 62\ \text{mm}$$

From the results of these calculations can be produced for shafts with carbon steel material for machining S 45 C needed Ø62 mm for the design of the construction of load lifting machines.

3.5 Gear Counting

Using formulas (6), (7) and (8) the calculation of the next machine construction needs, namely straight gears, can be started by calculating tangential forces.

$$tangential\ Force\ (F_{t1}) = \frac{102 \times P_d}{v_1}$$

$$tangential\ Force\ (F_{t1}) = \frac{102 \times 171.7}{10.07}$$

$$tangential\ Force\ (F_{t1}) = 1739.17\ \text{kg}$$

Furthermore, a flexible load calculation is required in order to be able to receive pressure on the collision gear.

$$Bending\ load\ (F_{b1}) = \sigma_A \times m \times Y_1 \times fv_1$$

$$Bending\ load\ (F_{b1}) = 30 \times 2.5 \times 0.383 \times 0.373$$

$$Bending\ load\ (F_{b1}) = 10.71\ \text{kg/mm}$$

Once the bending load and tangential force are known, the width of the gear can be determined to move the load between the servo motor and the machine construction shaft.

$$width\ of\ gear\ (b) = \frac{F_{t1}}{F_{b1}}$$

$$width\ of\ gear\ (b) = \frac{1739.17}{10.71}$$

$$width\ of\ gear\ (b) = 162.39\ \text{mm} = 163\ \text{mm}$$

Straight gear counting can begin with a general calculation of the gear in order to know the required diameter, number of gears, modules, gear comparison and other specifications for straight gears.

3.6 Servo Motor Needs Analysis

In the previous calculation, the power needed to lift a load of 350 kg amounted to 171.7 watts and this condition requires a moment of inertia of 0.58 kg/cm^2. Servo motors are selected based on the appropriate power then the power requirements at the load must be supplemented by 50% of the power as a safety factor in the selection of servo motors so that power is obtained for servo motors of 257.55 watts. This became the basis of researchers in determining the need for servo motors for components in the design of machine construction. Based on the data collected, the researchers concluded that servo motors that are in accordance with the needs of machine construction design, namely heavy duty servo motors with a power of 14.7 kW and torque of 70 N.m in accordance with servo motors that have been available from manufacturers.

3.7 Machine Construction Frame Calculation

Using the permissible steel voltage formula according to the formula (9), it can be determined the voltage that occurs in the Wide Flange Beam frame of 300 x 300 and compared to the carbon steel clearance voltage of 1600 kg/cm^3.

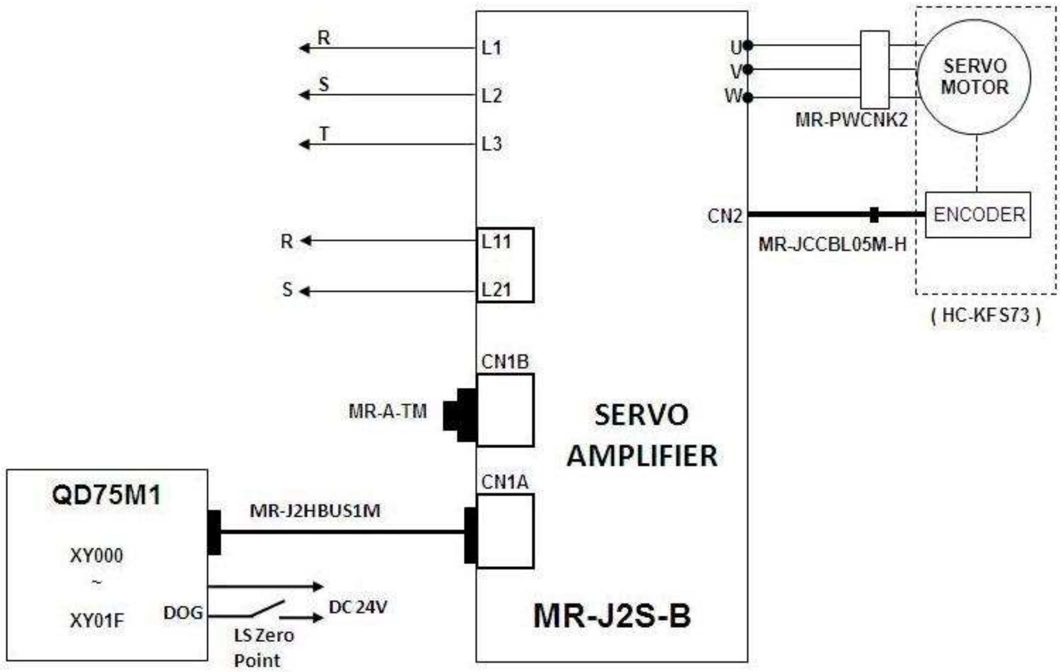

Figure 2. Servo Motor Wiring Diagram

$$Steel\ voltage\ (s) = \omega \times \frac{N}{A}$$

$$Steel\ voltage\ (s) = 1.198 \times \frac{434.25}{46.78}$$

$$Steel\ voltage\ (s) = 11.121\ \mathrm{kg/cm^3}$$

$$Steel\ voltage\ (s) = 12\ \mathrm{kg/cm^3}$$

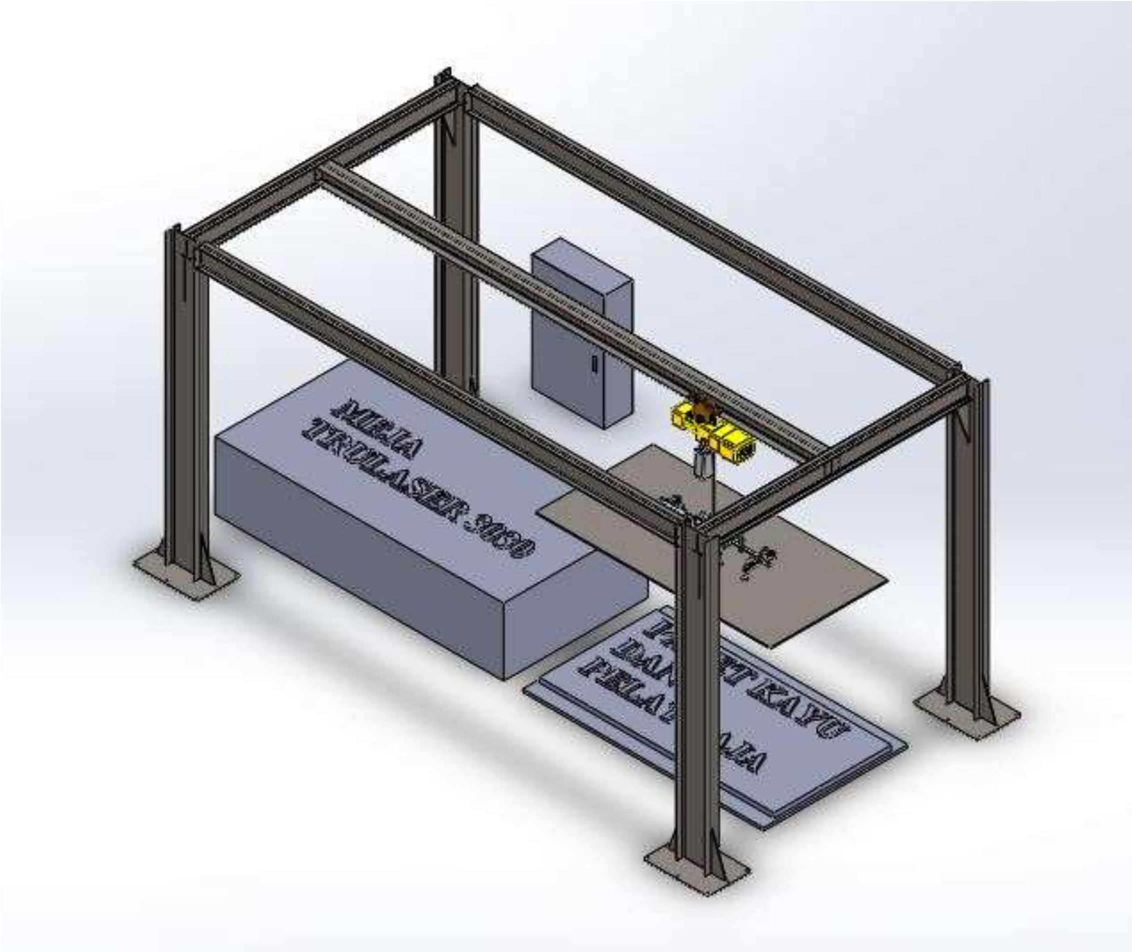

Figure 3. Mechanical Design of Steel Plate Transporting Machine (Isometry)

4 Conclusion

The ability of the gripping vacuum can be known from the suction motor's ability to withstand the load of each cubic meter in one hour and the power generated from the motor. The value of suction motor power and load-bearing ability can be seen from the volume owned by the steel plate which is 0.045 m^3 with a surface area of 2.98 m^2. The motor which has a suction power of 48 m^3/h and a power of 1.3 kW is able to withstand a steel plate load more than 15.0 mm thick with dimensions of 2.44 m x 1.22 m. In the design of this machine construction, researchers made calculations with existing formulas to obtain the optimal shaft diameter for the material S 45 C as carbon steel used in machine construction according to JIS (Japanese Industrial Standard) standards. From the calculation obtained the results for the best shaft diameter with grove pin as a support, namely Ø62 mm with torque that can be achieved τ_a = 4.83 kg/mm^2. In the selection of transmissions, the author uses straight gear transmission as a reinforcing material can be made in general and many companies are able to make straight gears with S 45 C material. From the results of these calculations, straight gears as transmissions needed by the construction of the clutch vacuum machine can be made with a gear width of 163 mm, the diameter of the gears on the servo motor 96.15, and the diameter of the gear on the shaft is 125 mm and the gear ratio is 4:3. Through the calculation of the above formula, it can be known that determining the specifications of the servo motor requires calculating the power plan where the value is 171.7 watts with the possibility of increased power due to overload of 50% of the planning. Taking into account the steel plate material has a large surface area so that heavy duty servo motors are needed as the main mover so that it is safe in the process of lifting materials with a power of 14.7 kW and torque of 70 N.m. Calculation of the machine construction frame is intended so that the frame of the construction can withstand the overall load of the construction so that there is no work accident due to frame fatigue and cause the construction of the machine to collapse. Through calculations, the construction frame of the machine requires a voltage of 12 kg/cm^3. The clearance voltage of steel is known to be 1600 kg/cm^3. This result stated that construction with a wide flange beam frame of 300 x 150 'good and safe' is used in machine construction as a frame.

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