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Design and Study of Advanced Cranes with Robotic ARM

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***Abstract*– Cranes are one of the essential industrial equipment for material handling jobs and manufacturing industries. And Robots are something that can be better than the human arm as they can be utilized 24 hours a day. They also help in increasing productivity by reducing the cycle time and also increasing the quality of the product because of fewer errors and high precision. In this research paper, We publish our work and research on a completely new concept of assembling a robotic arm to an overhead crane. We have carried out detailed research about cranes and robotic arms as well as done the necessary calculation with the help of some research papers and books that are given in references. Along with that, design of the model is also done based on calculations.**

Keywords*– Alliance, Crane, Robotic Arm,

1. INTRODUCTION

This research paper will present the work done on a completely new and innovative idea of assembling an industrial robotic arm to the overhead crane and make a clear understanding about where and how it could be used in different areas, and we will discuss the design procedure and general calculations of all the parts used in this model, and nowadays some of the companies are also working on this idea.

Objective

To create a smart, flexible, and multiple application workspace for a warehouse/workshop using Crane with a Robotic arm.

Basic Idea :– This research which was carried out between the 5th of August to 10th of March 2022, had includes project reviews under experience professors

Crane :– An overhead crane consists of parallel runways with a traveling bridge spanning the gap. Overhung cranes have a huge work envelope and can pretty much reach every corner of a warehouse or assembly line. But, they are not programmable and serve only for a limited purpose of just weight lifting.

Robotic Arm :– A robotic arm is a type of mechanical arm, usually programmable. A robotic arm can serve a lot of applications such as part assembly, lifting jobs with minimal changes in the front-end attachment. But, it is mounted over a rigid surface and so has a very limited work envelope, and usually zero mobility.

Advanced cranes with robotic arm :– Mounting a robotic arm to an overhung crane overcomes both the disadvantage of a limited number of applications (crane) and a limited work envelope (robotic arm). Combining these two enhances the number of applications and increases the level of automation and increases the work envelope. The robotic arm attains enhanced mobility due to the crane and can deliver its variety of functional applications at any desired location on the assembly line/warehouse.

2. METHODOLOGY

This project work which was carried out between the 5th of August to 10th of March 2022, includes project reviews of experienced professors.

We have followed the following steps to carry out the complete work of the project.

1. We started with defining the problem statement followed by analysis.
2. We moved to the design considerations and calculatioN for the model of the crane.
3. Based on calculations and constraints we designed the CAD model of the crane and robotic arm.
4. Each part of the CAD model is then analyzed on ANSYS with extreme load conditions.
5. The CAD model is also simulated on CATIA Kinematics.
6. Lastly based on the result of analysis and simulation the necessary changes were made in design and CAD.

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3. MATERIALS, ABBREVIATIONS AND UNITS

TABLE. 3.1 MATERIALS

Material	Yield strength (MPa)	Ultimate Strength (MPa)
Mild steel	350	440
Rolled steel	310	461
Stainless Steel	215	505
Hard Steel	550	450

TABLE. 3.2 ABBREVIATIONS AND UNITS

Parameter	Denotation	Unit
Moment	M	N/mm^2 or N/m^2
Mass	m	kg
Moment of inertia	I	N/mm^4
Distance from the neutral axis	Y	m/mm
Stress	σ	N/mm^2 or N/m^2
Weight	W	N
Force	P	N
Length	L	m
Effective length	L_e	m

4. CALCULATIONS

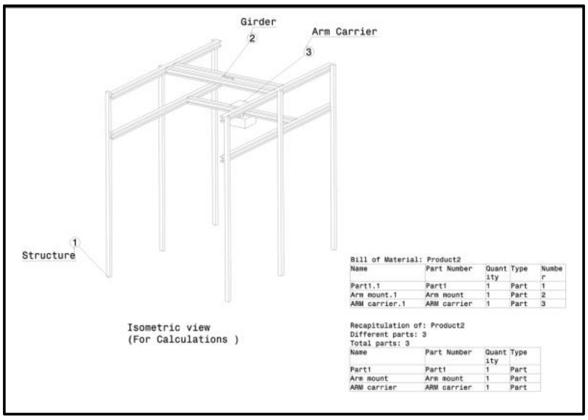

Fig. 4.1 (3D view of parts for which the calculations are performed.)

4.1) Calculations for Girder (for Robotic Crane) :

Girder undergoes a bending moment. (Always maximum bending moment for a point load is achieved, when the load is applied at center)

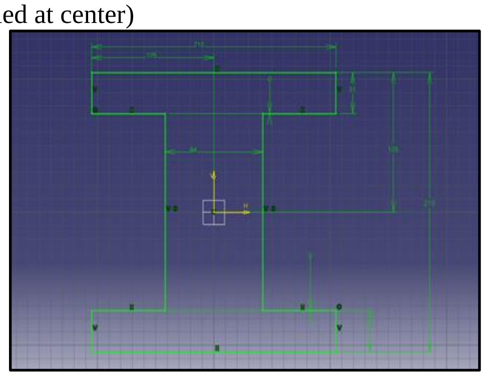

Fig. 4.1.1 - I- Section for Grider (for Robotic Crane)

Flexural Formula

$(M/I) = (\sigma/Y)$

$I = (BD^3 - bd^3) / 12$

$I = (210 * 210^3 - 126 * 148^3) / 12$

$I = 1.28 * 10^8 \text{ mm}^4$

$\sigma_{max} = 310$ (yield strength for hot rolled steel)

$M = (\sigma_{max} * I) / y$

$= (310 * 1.28 * 10^8) / 105$

$= 3.78 * 10^8$ N.mm

$M = 3.78 * 10^5$ N.m

Maximum Moment when load at center

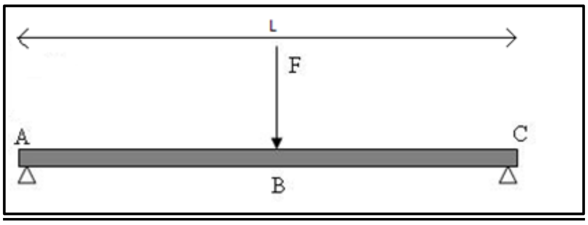

Fig. 4.1.2 - FBD for Grider (for Robotic Crane)

$M = W * L/2$

$W = (3.78 * 10^5) / 17.5$

$W = 21600$ N

$W = mg$

$21600 = m * 9.8$

$m = 2204.0816$ kg

Girder undergoes shear (Maximum force is achieved when load is applied at center)

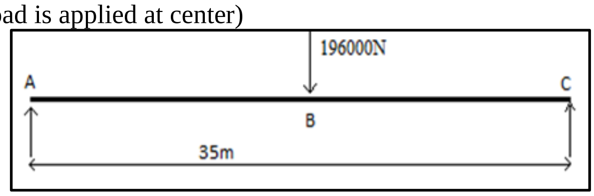

Fig. 4.1.3 - FBD for Grider (for Robotic Crane)

$W_{max} = 19000$ N

$R_A = 98000 \text{ N} = W/2$

$R_B = W\backslash 2 = 98000$ N

By shear force diagram,

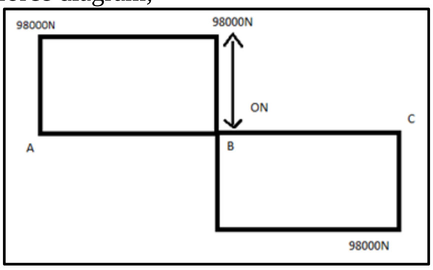

Fig. 4.1.4 - SFD for Grider (for Robotic Crane)

$Sf_{AL} = 0$

Sf @ $A = 98000N$

$Sf_A = 98000N$

$Sf_{LB} = 98000N$

Sf @ $B = -196000N$

$Sf_B = -98000N$

$Sf_{LC} = -98000N$

$Sf_C = 0N$

5.2) Calculations for Girder (for Conventional Crane)

Girder undergoes a bending moment. (Always maximum bending moment for a point load is achieved, when the load is applied at center)

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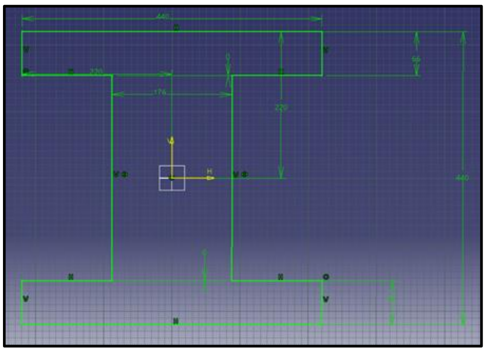

Fig. 4.2.1 - I- Section for Grider (for Conventional Crane)

Flexural Formula

$(M/I) = (\sigma/Y)$

$I = (BD^3 - bd^3) / 12$

$I = (440 * 440^3 - 264 * 308^3)) / 12$

$I = 2.4806 * 10^9 \text{ mm}^4$

$\sigma_{max} = 310$ (yield strength for hot rolled steel)

$M = (\sigma_{max} * I) / y$

$M = (310 * (440 * 440^3 - 264 * 308^3)) / 12 * 220$

$M = 3.4954 * 10^9 \text{ N.mm}$

Maximum Moment when load at center

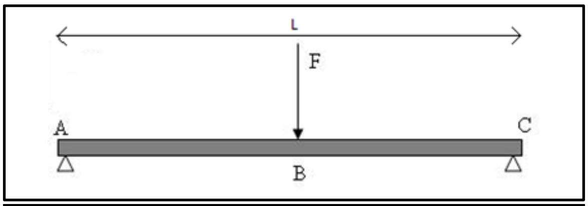

Fig. 4.2.2 - FBD for Grider (for Conventional Crane)

$M = W * L/2$

$W = (3.4954 * 10^6) / 17.5$

$W = 199737.1429 \text{ N}$

$W = mg$

$199737.1429 = m * 9.8$

$m = 20381.3411 \text{ kg}$

4.3) Calculations for Structure of long travel :

Structure for long travel, undergoes bending moment. (Always maximum bending moment for a point load is achieved, when the load is applied at center)

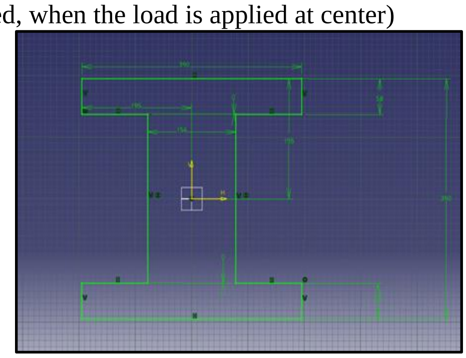

Fig. 4.3.1 - I- Section for Structure of long travel

Flexural Formula

$(M/I) = (\sigma/Y)$

$I = (BD^3 - bd^3) / 12$

$I = (390 * 390^3 - 234 * 274^3) / 12$

$I = 1.56274 * 10^9 \text{ mm}^4$

$\sigma_{max} = 310$ (yield strength for hot rolled steel)

$M = (\sigma_{max} * I) / y$

$= (310 * I) / y$

$= 310 (390 * 390^3 - 234 * 274^3) / (12 * 195)$

$= 2.42712 * 10^9 \text{ N.mm}$

$M = 2.42712 * 10^6 \text{ N.m}$

Maximum Moment when load at center

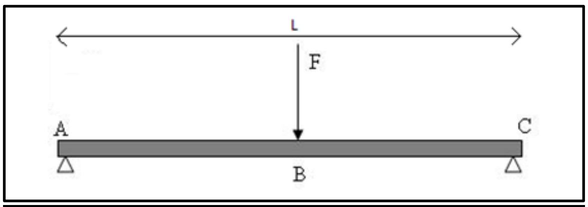

Fig. 4.3.2 - FBD for Structure of long travel

$M = W * L/2$

$W = (2.42712 * 10^6) / 12.5$

$W = 194169.5565 \text{ N}$

$W = mg$

$m = W / g$

$m = 194169.5565 / 9.8$

$m = 19813.22005 \text{ kg} \approx 20000 \text{ kg}$

4.4 Calculations for Structure of Long travel :

Structure for long travel in shear (maximum shear force is achieved when the load is applied at the center). We Take the weight at the end so that we get maximum input for long travel (for shear calculations)

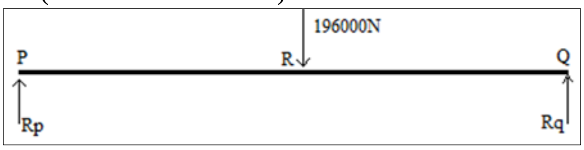

Fig. 4. - FBD for Grider (for Robotic Crane)

$W_{mzx} = 196000\text{N}$

Shear force will be maximum when the load will act at the center.

$R_p = W/2 = 98000\text{N}$

$R_Q = W/2 = 98000\text{N}$

By shear force diagram,

$Sf_{PL} = 0$

$Sf @ P = 98000 \text{ N}$

$Sf_P = 98000 \text{ N}$

$Sf_{LR} = 98000\text{N}$

$Sf @ R = -196000\text{N}$

$Sf_R = -98000\text{N}$

$Sf_{LQ} = -98000\text{N}$

$Sf @ Q = 98000\text{N}$

$Sf_Q = 0 \text{ N}$

4.4) Calculations for Structure of Pillar:

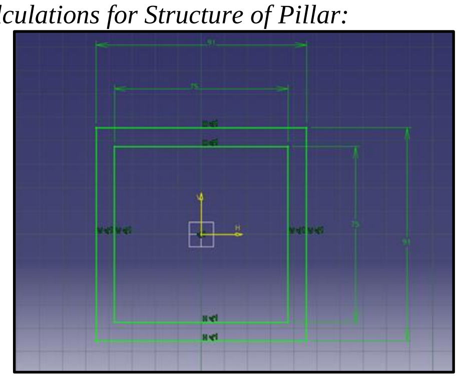

Fig. 4.4.1 - I- Section for Structure of Pillar

International Journal of Engineering Research & Technology (IJERT)
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Vol. 11 Issue 05, May-2022

Pillar undergoes Buckling.

$P = (\pi^2 EI) / L^2$ $(L_e = L)$

$1000 * 9.8 = (\pi^2 * 210 * 10^3 * (a^4 - (a-16)^4)) / (12 * 8^2 * (10^3)^2)$

a = 90.52942911 mm

$a \approx 91$mm

Inner Dimension = a-16 = 75mm

Outer Dimension = a = 91mm

4.5) Robotic Arm Carrier :

Robotic Arm carrier is designed through simple stresses and strain calculation.

Material : AISI Type 304 stainless

σ_{yield} = 215 Pa = 215 Nmm^2

FOS = 2.5

$\sigma_{t\ (allowed)} = \sigma_{yield}$ / FOS = 215 / 2.5 = 86 N/mm^2

σ_T = 86 N/mm^2

86 = (20000 * 98) / ((π/3) * 32.5 * x)

x = 66.96 mm (thickness)

$x \approx 70$ mm

σ_T = 86 N/mm^2

$\sigma_T' = P / A$

$\sigma_T' \not< 86$ N/mm^2

σ_T' = (20000 * 9.8) / (70 * 200)

σ_T' = 14 N/mm^2

Hence, the design is valid.

Why 200 mm is taken as x_1 :

➢ The diameter of circle is 65mm. So we have to put the length of the cross-section greater than 65mm (i.e. 200 mm).

➢ For proper force distribution, to the downplate. We have to increase the length of the cross-section (200 mm), proportional to the downplate.

5. DESIGN (CAD MODEL) :

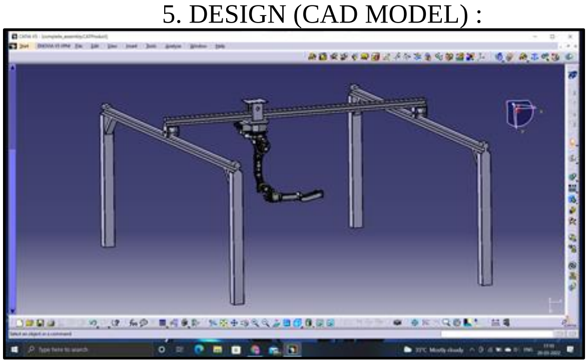

Fig. 4.2 Design (CAD Model) - Advanced Crane with Robotic Crane

6. ANALYSIS :

The developed 3D model is imported into ANSYS 2021 R2 software. A Crane is designed on a 20 tonne load. The physical and mechanical properties for the analysis are supplied as per the values in the table . The stress value and total deformation of the crane parts are obtained separately.

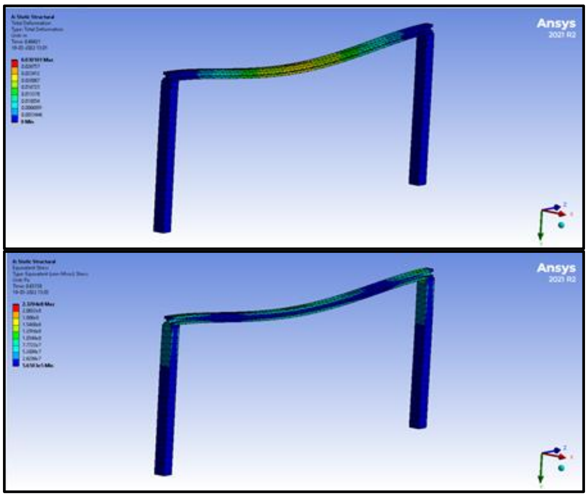

Fig. 6.1 Ansys of long travel

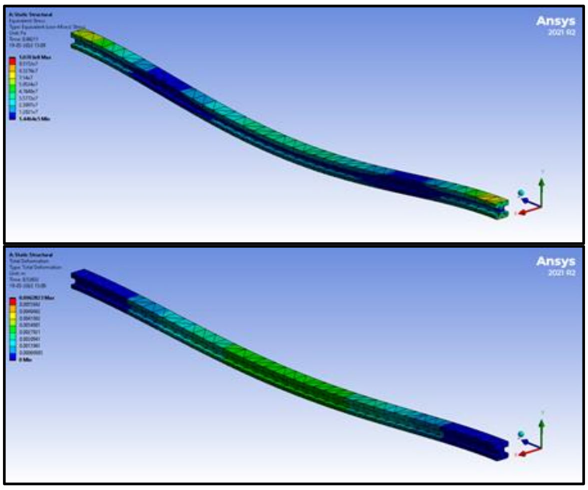

Fig. 6.2 Ansys of cross travel

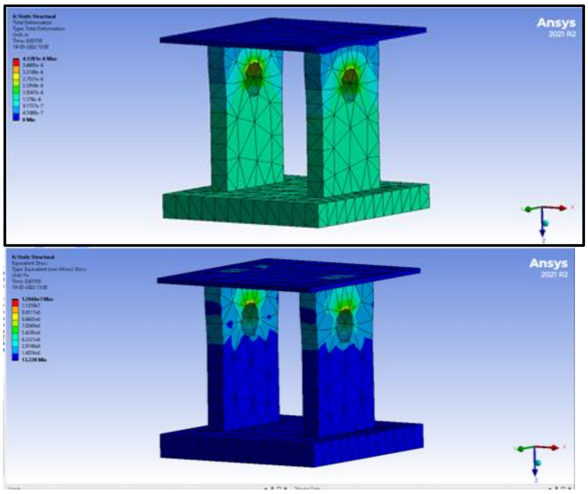

Fig. 6.3 Ansys of arm carrier

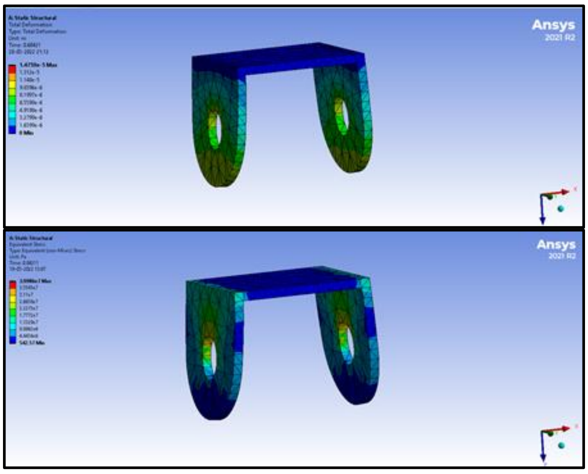
Fig. 6.4 Ansys of wheel carrier

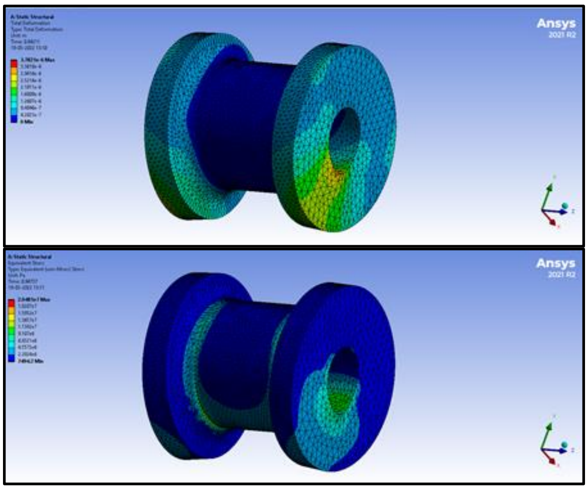
Fig. 6.5 Ansys of wheel

7. RESULT & DISCUSSION:

The following results are obtained based on the Analysis. For all parts, we do analysis on the extreme load conditions. in that we consider all factors like fixed surface, friction surface, etc.

1. Long Travel has a 0.030 m deflection. In this we had two long travels which will support the load, along with the load carrier, hence force will be distributed in both the travels, hence deflection considered negligible.
2. Cross Travel has a 6.28 mm Deflection. normally industries had this much deflection.
3. The Arm Carrier has a 0.004 mm deflection, Which is negligible.
4. The Wheel Carrier has 0.01 mm deflection.
5. Wheel has a 0.0037 mm deflection, which is also negligible.

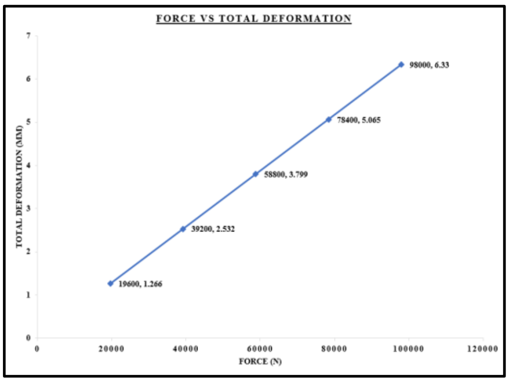

Fig. 7.1 Force vs Total Deformation for cross travel

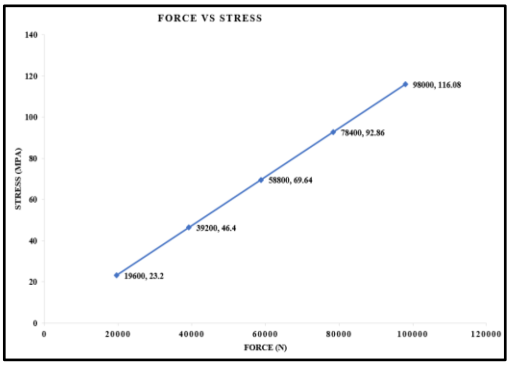

Fig. 8.1 Force vs Stress for cross travel

The following Factor of safety are found based on analysis,

TABLE 8.1 FACTOR OF SAFETY (FOS) OF DIFFERENT COMPONENTS (PARTS)

Part Name	Factor of safety(FOS)
Long Travel	1.5
Cross Travel	2.8
Arm Carrier	2.5
Wheel Carrier	5
Wheel	10.7

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