ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 4, Issue 9, September 2019

Implementation of 6 Degrees of Freedom Movement on a Gantry Loader Crane with 6 Different Motion Points

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***Abstract:*-- The urge of getting properties of different components in a single engineering component is rising as technology surges. Typically, we desire a component must possess low wear resistance or thermal conductivity at its surface also with high interior toughness. For this manufacturing of Functionally Graded Material (FGM) becomes essential. Constitutional variation is the main factor on which the performance of FGM is dependent. Hence, it is mandatory to optimize the compositional distribution in FGM.There are many techniques which have been imposed to manufacture FGMs, including physical and chemical vapor deposition, sintering, plasma spraying, electroplating, Powder metallurgy and combustion synthesis. In this research FGM has been fabricated by powder metallurgy which is efficient and reliable method. This technique includes processes like cold compacting and sintering.By this method microstructure, composition and shape can be controlled. In this research FGM of Silicon carbide (Sic) and Aluminium (Al) has been made successfully. Also, test of mechanical properties and microstructure studies has been carried out.**

Index Terms:- Functionally graded materials, FGM, Powder Metallurgy, Aluminium (Al), Silicon Carbide (Sic).

I. INTRODUCTION

Mobile crane systems combined with other technology has been the actuator of modern day infrastructure development. Crane systems have helped in overcoming the hindrance that erupt in construction works. The crane system were designed to overcome several issues that slowdown the construction work. As constructions became more complex and as demand of modern day increased, crane technology became more flexible and incorporated new adjustable features which developed the term cooperative crane manipulator.

Despite of several high technical advancement a single cooperative crane system fails to provide all 6 degrees of freedom movement. The research here focuses on bridging the gap between limitation of a cooperative crane system and 6 degrees of freedom movement by suggesting new modeling changes in various crane system.

A conventional crane system uses pulley and rope system for movement of material in vertical direction and fixed joint or ratchet system for circular motion.

A cooperative crane manipulator combines these motions at different points to provide maximum coverage of area and to achieve maximum degrees of freedom in movement.

Crane System

Major types of the crane

Mobile crane, Gantry crane, EOT crane, Over-head crane, Truck crane, All-terrain crane, Rough-terrain crane, Tower crane and Crawler crane are few different types of cranes that are used for various construction, transportation and assembly purposes.

Structure of a crane

The structure of a crane can be mainly divided into six sections: boom system, electrical system, hydraulic system, turntable assembly, operator's cab and chassis. The boom system mainly comprises the main boom, jib, telescopic mechanism and boom end sheave. The electrical system of superstructure primarily comprises the electrical systems of main boom, jib and turntable. The chassis comprises the body structure, transmission system, steering system, brake system, traveling system, chassis electrical system as well as the hydraulic system of undercarriages.

Structure of Gantry crane

Gantry crane gets its name from the steel bars that rest over side supports to provide a bridge network used to straddle an object

Gantry crane have wide applications which ranges from construction, manufacturing, assembly line. They can be used for the most wide load range depending on their size and shape.

Another alternative name given to Gantry crane is portal cranes, the word is used to describe the empty space that the gantry straddles.

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Gantry crane in a way is like an overhead crane (or bridge crane), just like in an overhead crane, gantry crane also straddles its workload. The major difference between the two is of that gantry cranes are moved through wheels and rails whether it be the whole structure or the pulley placed on the bridge.

A fixed location is chosen for the supporting structure of an overhead crane, a movable hoist along a rail or beam is attached. A movable beam mounted hoist can also be included along with the entire structure in a gantry cranes.

Lateral movement system: Gantry cranes perform the lateral movement on two sets of wheels placed on either side of the bridge. The cabin located along the land-side wheel controls the lateral movement.

Vertical frame and braces: The steel frame, beams, bridge, boom and the operating load all rest on the vertical frame and braces that ensure stable support for the movement of the load across.

Crane boom: Crane boom spans from land-sides on either side to the other side making a horizontal bridge. Beams can be raised to higher level depending upon the requirement.

Hook: The vertical motion for transportation and movement of load is done with the help of a hook which supports the load for safe transportation. A spreader is attached to span the container in container cranes.

Operating cabin: This is based on the site of work. Most of the times it is placed on the lower end close to wheel. In new advanced method the whole crane is operated from open space using a compact digital or analog controller connected to command centre through electric cords which connect it to the main control setup attached on the lift.

Few places are using mechatronic arrangements to achieve the job from a distance.

Six Degrees of Freedom:

Six degrees of freedom is a specific parameter count for the number of degrees of freedom an object has in three-dimensional space, such as the real world. It means that there are six parameters or ways that the body can move.

Translation – Moving along the different axes X, Y and Z. Moving up and down along the Y axis is called heaving. Moving forwards and backwards along the X axis is called surging. Moving left and right along the Z axis is called swaying.

Rotation – Turning in order to face a different axis. Moving between X and Y is called pitch. Moving between X and Z is called yaw. Moving between Z and Y is called roll.

This concept is often used in engineering and robotics. a robotic arm with three segments and each jointed segment having six degrees of freedom, it can be said that the robot arm has 18 degrees of freedom.

Motion constraints

It is possible to constrain the motion of the rigid body to certain translations and rotations. The following setting show how such constraints could be defined:

Translation Constraint:

No Constraint: The body is free to move in any direction.

Point: The body is fixed to a reference point.

Line: Motion of the body is restricted along the specified line.

Plane: Motion of the body is restricted in a plane. The plane is specified by its normal vector.

Rotation Constraint:

No Constraint: The body is free to rotate.

Fixed Orientation: No rotation is allowed. The body translates in a fixed orientation.

Axis: The body is only allowed to rotate about a fixed axis.

Stewart Parallel Manipulator: A mechanical system that uses several serial chains of computer controlled joints and processes. Six linear actuators are required or used to form a good parallel manipulator and the design developed by using this process is known as Stewart platform or Gough platform. Either a robot on base or one or more manipulators are used to perform the desired movements. They are different from serial manipulator as end effectors are directly connected to its base using separate linkages working simultaneously.

Design features: Each chain is in general short to provide rigidity to resist unwanted movement contrary to a serial manipulator. Any deviation in aggregation of movement or position is averaged by grouping of other chains and so cumulative effect is removed. Degree of freedom of each actuator is restricted and its own movement is based on its placement and positioning. There's a constraint on off-axis flexibility.

But a parallel manipulator is restricted in terms of working space. A serial manipulator is limited by geometrical and mechanical limits. At certain position due to variations of length being smaller workspace gets reduced this is termed as existence of singularities. A large constraint is produced due to gravitational effects which can result in failure of the manipulator. This implies that the movement and scope of manipulator are artificially limited to shorter distances.

Parallel manipulators have non linear behavior.

Cooperative crane manipulator:

It is a system where different movements are clubbed together in a single machine so as to achieve maximum number of degree of freedom. Cranes are required to several movements along with held up load and it needs high workability with least possible constraints.

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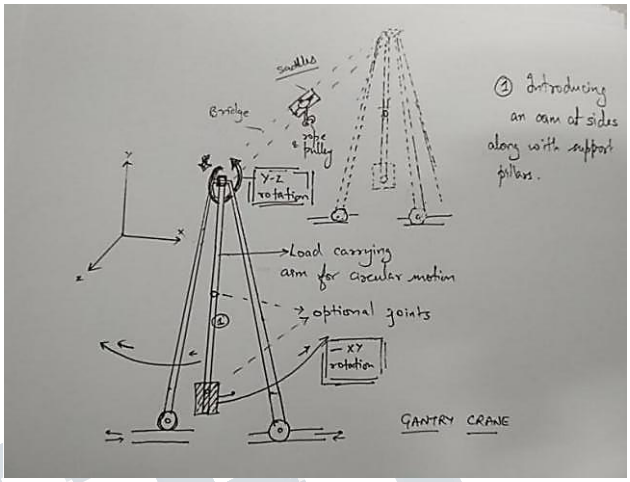
To achieve the above mentioned, several design changes and feasible movements are created and joined to create a whole sum movement.
The design changes mentioned in this research paper focus on similar idea and hence suggest a type of Cooperative crane.

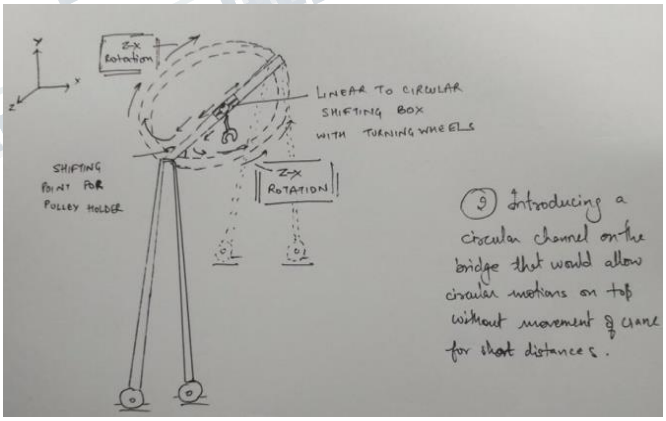
II. SYSTEM DESCRIPTION:

Idea: The basic idea is to ease the working of a construction gantry crane with modification on several joints which allows the crane to make complete movement on each degree of freedom.
As per the design of a gantry crane there are wheel at the base of pillar which move on the rail providing lateral movement.
The Pulley provides vertical motion.
The upper channel also called bridge provides horizontal movement.
There is no circular or rotational motion in a traditional gantry crane. The new changes are based on implementing rotational movement on the gantry crane so that more diverse movements and transportation of material become possible and feasible. A traditional gantry crane is shown in image.

Features:
The side pillars provide support and lateral movement.
A movable arm with three degree of freedom joint would be placed on both the sides such that the joint are on the top part of support on the edge of vertical support and bridge.
A circular channel will be placed along with the bridge such that it would circumscribe the bridge.
Design changes:
As a change in the traditional design there would be no removal of previously operating systems rather there would be modifications in the existing design. Apart from the modification of the previously available joints and parts, the new additions would complement the already existing design and structure which would help in achieving a better movement of load across the planes and axis.
New addition:
There are three major additions suggested to the already existing conventional design
i. A rotating arm is introduced on each side between the supporting pillars. This rotating arm would sweep the plane created through Vertical and Lateral axis on both the sides of the crane. Along with this the rotating arm can also be attached through a universal joint which would allow it to make a partial movement in the plane created between vertical and horizontal axis.



1. Introducing an arm at sid es along with support pillar
ii. A circular channel is to be placed on the bridge such that it circumscribes the top bridge where the bridge appears as a diameter of the circular channel. This circular channel helps provide a circular motion in the plane created between Lateral and Horizontal axis on top of the crane (X-Z plane in diagram).



2. Introducing circular channel on the bridge that would allow circular motions on top without movement of crane for short distances.
iii. A robotic arm or a rotating arm is to be introduced exactly at centre of the bridge connecting to extreme supports of the crane. This arm would help in a circular motion sweeping the area between Horizontal and Vertical axis (Y-Z plane in diagram). In case of a robotic arm several more motions can be achieved on the same arm details of which can be skipped at this particular moment.

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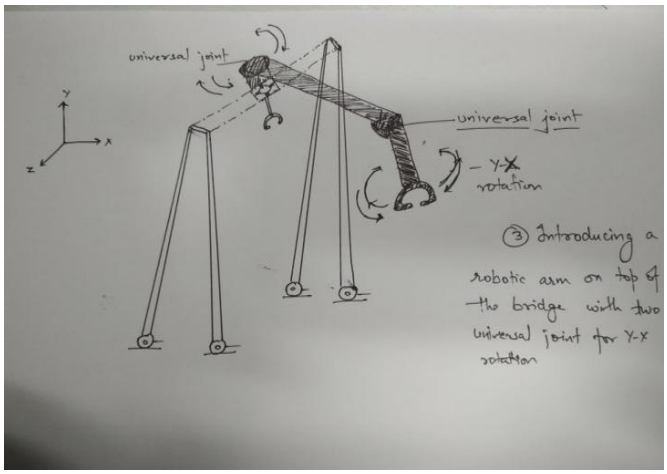

3. Introducing a robotic arm on top of the bridge with two universal joints for Y-X rotation

Scope of new design:

The new design has many practical advantages and benefits. They would reduce the overall work time and increase the efficiency of the gantry crane overall by increasing the number of task and area of work-ability of the crane.

Few considerable scopes of the design changes are as follows.

1. Greater heights can be achieved using new arms
2. The lateral distances can be increased with the help of side arms.
3. More than one task can be performed at a time using various arms connected to the crane
4. Speed of working can be increased and time can be reduced

Advantage:

1. Eliminates or reduces the requirement of another helping/ supporting crane as majority of the movement and lifting tasks can be performed single handedly by the this gantry crane.
2. Increases the area of approach with introduction of new arm which increase the reach of crane in all three axis.
3. Reduces the fuel cost of the crane by reducing the wheel based movement of crane which can be compensated by use of long arms.

III. PROBLEM FORMULATION

Gubler's formula:

$$M = 6n - \sum_{i=1}^{j} (6 - f_i) = 6(N - 1 - j) + \sum_{i=1}^{j} f_i$$

Planar and spherical movement:

$$M = 3(N - 1 - j) + \sum_{i=1}^{j} f_i,$$

The conventional methods of calculation of degree of freedom ignore geometrical constraints which lead to inaccurate results. A relationship is derived using equation and is used for determining the number of degrees of freedom of a parallel robot N.

$N = \sum_{(i=1)} Lmi - \sum_{(j=1)} BC_j$

With:

B is the number of independent closed loops, equal to (n_c − 1), where n_c is the number of parallel chains;

Mi is mobility of joint i; L is total number of joints; C_j: number of constraints of the j^{th} loop. For a planar loop C_j = 3, for a spatial loop C_j = 6.

IV. METHODOLOGY

Movements around axis

Every arm and section of the crane would have a specific set of functions to be performed based on its axis of movement and area swept under the specific plane.

* The wheels would allow the lateral movement on the rails in X axis.
* The bridge will allow horizontal movement on the trail placed on bridge in Z axis.
* The Pulley and rope system attached to the bridge will allow vertical movement in Y axis.
* The Side arms (1) will rotate in Y-X plane increasing the scope of lateral and vertical distance achieved.
* The circular trail circumscribing the bridge would allow the pulley rope system to travel small distances around the circular area without moving the crane on rail. Circular motion would be in Z-X plane.
* The robotic arm would allow circular/ rotary movement in Y-Z plane and would help cover vertical distances above the bridge

All these movements together provide 6 degrees of movement to the crane. Each division provides just one degree of freedom to the system and hence no division carries any sort of extra stress. The calculation of degree of freedom of each division and every joint is based on Gubler's Formula and understanding of simple movements on axis and in planes.

This arrangement although would create difficulty in maintenance and assembling of the crane

Some of the Challenges faced would be as mentioned.

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1. High maintenance cost of machine due to excessive parts of the machinery which perform different tasks for specialized performances.
2. High cost of assembling due to complex design and highly updated features.
3. Increased weight of machine due to added arms, trails and supporting trusses etc.
4. Due to added weight and increased volume of the crane the balance has to be checked during lateral movement.
5. Balancing of wheel due to increased width of the crane.

V. CONCLUSION

The new design changes will help ease out the movement and lifting of load at difficult points in construction sites and manufacturing unit.
The problem of increased weight and complexity of the overall machine can be dealt with few efforts and it is expected that the design change would ultimately increase the speed and hence the overall efficiency of the crane.
The calculation related to design change needs to be done separately to get better understanding of the situation but such calculation is beyond the scope of this research paper.
In future extension of this paper design calculation can be taken into consideration and an extensive study can be done to understand the level of efficiency that can be increased using this method.

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