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Outrigger Arm for a Defence Utility Vehicle - Kinematic Design and Load Analysis

Chandu Raghav R S
Mechanical Engineering
MEC Engineering College Trivandrum, India

Abstract—

A defence utility vehicle with outrigger arm can be used for special purpose operations like mine clearance, dredging, cleaning etc. This vehicle weighs a maximum of about twenty tons. The vehicle with this type of arm can walk or crawl on irregular marshy surfaces, can lift the entire vehicle body from lower level to higher level and vice versa especially while travelling on steep and rocky grounds. It should also give anchorage during the special operations along the banks of water bodies and also in marshy areas. The work is about the kinematic design and load analysis of the outrigger arm. Detailed study of the outrigger arm operations, design requirements, load cases, kinematic synthesis, and load analysis for various load cases of the stabilizer arm were considered in this work. A detailed static force analysis was done. The load analysis for various positions of the outrigger was done using MATLAB.

Keywords— kinematics, transmission angle, Slider-crank, inversions, Degree of freedom, load analysis

I. INTRODUCTION

The defence utility vehicle with this type of arm can do variety of jobs like mine detection, walk or crawl on irregular marshy surfaces, can lift the entire vehicle body from lower level to higher level and vice versa (especially while travelling on steep and rocky grounds).This vehicle arm can raise and lower the vehicle body from ground surface. In this work we are dealing with kinematic design and load analysis of the outrigger arm. The outrigger arm configuration and actuation trade-offs are finalized. Structural and kinematic diagram of outrigger arm were completed and DOF was calculated. Suitable kinematic inversion was selected. The kinematic synthesis of the required mechanism was completed. The transmission angle study of the slider crank mechanism was also carried out. Static force analysis was done at various positions, as the load analysis forms the important input for doing the structural analysis. The load analysis for various positions of the outrigger was done using MATLAB.

II. METHODOLOGY

A. Overall vehicle configuration

The vehicle is about 6.8m long, 2.69m wide and 2m high. The weight of the vehicle is considered to be about 20 ton.

B. Kinematic synthesis

The objective of kinematics is to develop various means of transforming motion to achieve a specific kind needed in applications. The basic steps in kinematic synthesis are type synthesis, number synthesis and dimensional synthesis.

Type synthesis refers to the kind of mechanism selected. Option can go in favour of a gear combination, a belt pulley combination, a linkage or a cam mechanism. During the early stage of synthesis, one may have to consider design aspects like space consideration, safety consideration, Overall economics, Manufacturing process, Material selection etc.

Number synthesis determination of the number and order of links and joints necessary to produce motion of a particular DOF. Number synthesis is based on the most obvious external characteristics of a kinematic chain, namely, the number of links together with number and type of joints required for a specified motion.

Dimensionalsynthesisaims at determining significant dimensions of links and the starting position of links in a mechanism, to accomplish specified task and prescribed motion characteristics. Dimensional synthesis assumes that, through type synthesis, the most appropriate linkage is selected as solution for the problem.

C. Outrigger arm actuation trade-offs

The gear actuation and hydraulic actuation were considered for the stabilizer arm operation. Since the requirement is to produce high torque for the lifting of the body and space limitation, hydraulic actuation method is used.

D. Kinematic inversion

Every mechanism has a fixed link called the frame. Until a frame link has been chosen, a connected set of links are called kinematic chain. When different links are chosen as the frame for a given kinematic chain, the relative motion between the links are not altered but there absolute motion change drastically. The process of choosing different links of a chain for the frame is called kinematic inversion.

In an n link kinematic chain, choosing each link in turn as the frame yields n distinct kinematic inversions of the chain, n different mechanisms

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E. Slider crank mechanism

Third inversion of Slider crank mechanism is selected for making the outrigger arm.

F. Inversions of slider crank mechanism

A four link slider crank chain has four different inversions: (a) First inversion link 1 is fixed (Reciprocating engine/compressor). b) Second inversion link 2 is fixed (whit worth quick return mechanism, rotary engine). (c)Third inversion link 3 is fixed (crank slotted lever mechanism, oscillating cylinder). (d)Fourth inversion link 4 is fixed (hand pump, bull engine).

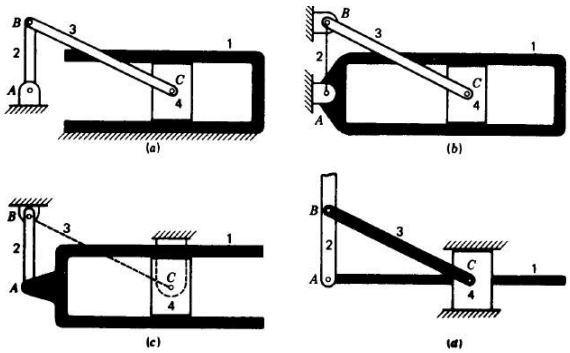

Figure1. Inversions of slider crank mechanism

G. Structural diagram of outrigger arm

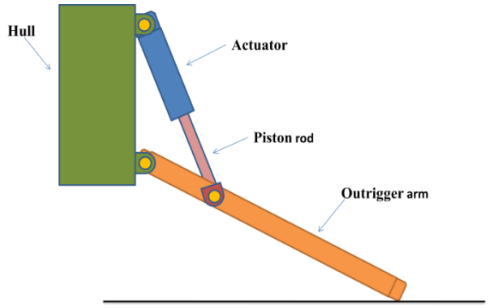

Figure2. Structural diagram of outrigger arm

H. Kinematic diagram of outrigger arm

The kinematic diagram shows the different links and joints present in the mechanism and how the mechanism supposed to move. During operation of outrigger, the utility vehicle is stationary. Therefore the vehicle is designated as the frame. The motion of all other link is determined relative to the vehicle. The various steps involved in this process were the identification of frame/hull, all the links, all the joints and the point of interest (X). The degree of freedom or mobility was calculated from the kinematic diagram drawn.

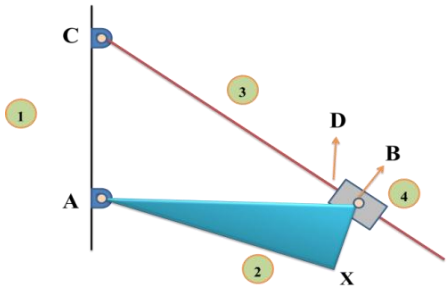

Figure3. Kinematic diagram

I. Mobility or degree of freedom

It is the minimum number of independent coordinates or parameters needed to describe configuration of a body in motion. To calculate the mobility (DOF), there are 4 links in the mechanism, as well as 3 joints and one slider joint. The degree of freedom (DOF) of a planar mechanism is given by the Gruebler's equation

$$F = \text{DOF} = 3(N-1)-2J-P \qquad (1)$$

N=4, J=4, P=0

F=1

Since the degree of freedom of the mechanism is one, only one actuator is required for the motion of outrigger.

J. Transmission angle

Transmission angle is defined as the angle between the output link and the coupler. It is usually taken as the absolute value of the acute angle of the pair of angles at the intersection of the two links and varies continuously from some

minimum to some maximum value as the linkage goes through its range of motion. It is a measure of the quality of force and velocity transmission at the joint. When transmission angle is 90 degrees, maximum output force can be obtained by applying minimum input force. A detailed study of transmission angle of slider crank mechanism was done with an objective of maximum effectiveness.

K. Geometrical parameters of the outrigger mechanism

The important parameters of outrigger mechanism are the frame (hull) length, outrigger arm length, standoff length, the hydraulic cylinder length, outrigger inclination with the ground horizontal (theta) and the hydraulic cylinder inclination with the outrigger arm (phi).

L. Load analysis

Machines are used to apply mechanical force, energy, or power for useful purposes. Mechanisms are used to transmit and apply force, as well as to generate desired motions. Load analysis forms the most important input for doing the structural analysis using the conventional design procedures using exact solutions or approximate solutions or with numerical methods like finite element methods. The load analysis was done considering the various two force members and three force members. The free body diagrams of different structural members were constructed. The load analysis for various positions of the outrigger was done using MATLAB method. The static force analysis was done considering the various two force members and three force members present in the mechanism. The free body diagrams of the members were constructed and load analysis was done on the MATLAB.

M. Static equilibrium

Newton's first two laws of motion are that, if a body is at rest, the sum of all forces acting on the body must be zero. Further, the sum of the moments of those forces about any point must also be zero. Thus for any member of the structure

$$\sum F_x = 0 , \sum F_y = 0 \quad (2)$$

$$\sum M = 0 \quad (3)$$

Where $\sum F_x$ and $\sum F_y$ are the sum of all forces acting on the body in the x and y directions, respectively (with respect to the reference coordinate system) and ∑M is the sum of the moments of those forces about any chosen point, o. The basis of the static force analysis of any structure is the algebraic solution of the static equilibrium equations written for every member of the system.

N. Free body diagram

A free-body diagram is a sketch or drawing of part or all of a system, isolated in order to determine the nature of forces acting on that body. The part appears to be floating because all the supports and contacts with other parts have been removed. All these supports and contacts are then replaced with forces that represent the action of the support. Thus, a free body diagram of a part shows all the forces acting on the part.

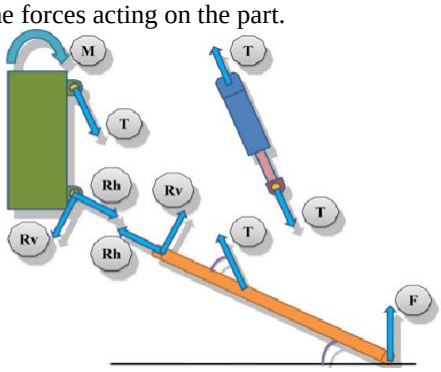

Figure 4. Free body diagram

III. RESULTS AND DISCUSSIONS

MATLAB is used for analysis of mechanism of the outrigger arm for the defence utility vehicle. The quantities computed are the actuator force, actuator length, vertical reaction, horizontal reaction and the net reaction on the outrigger arms.

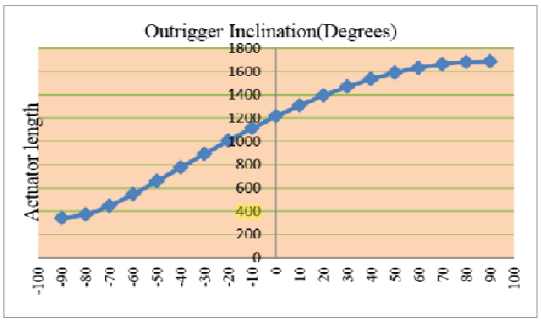

Figure5. Outrigger inclination Vs Actuator length

The Figure7 shows the variation of actuator length with the outrigger arm inclination with the ground horizontal. This will help us in selecting the stroke requirement of hydraulic actuator required to meet the requirement along with the idle length.

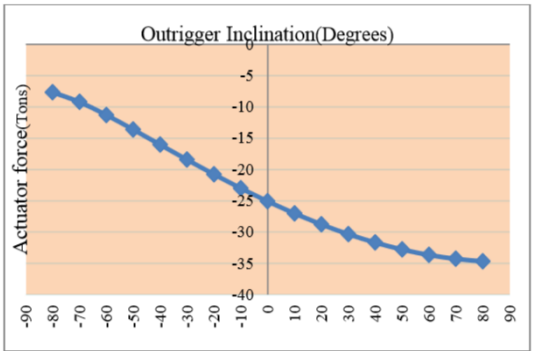

Figure 6. Outrigger inclination Vs Actuator force

The graph (Figure 8) shows the variation of actuator force with the outrigger arm inclination with the ground horizontal. The actuator force for various positions of outrigger arm has been calculated. From this we can select the class of hydraulic actuator required to meet our requirement and also find out the peak force output.

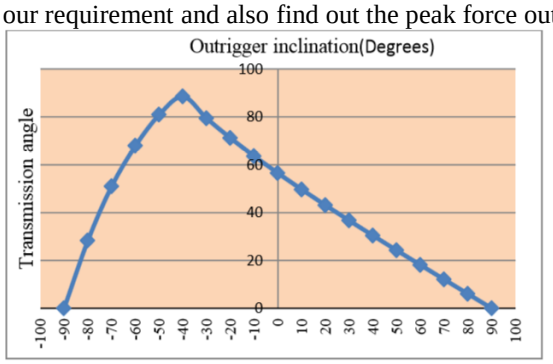

Figure 7. Outrigger inclination Vs Transmission angle

The graph (figure 9) shows the variation of transmission angle for various positions of outrigger arm with the horizontal. From this we can find out the regions were we can produce maximum output force with minimum input force from the actuator for the whole range of outrigger arm motion from -90 degrees to +90 degrees.

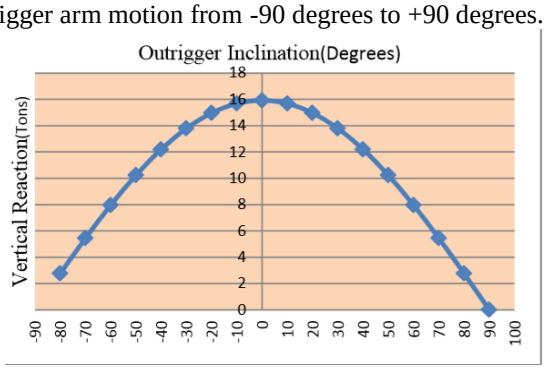

Figure8. Outrigger inclination Vs vertical reaction

The graph (Figure 10) shows the variation of vertical reaction with the outrigger arm inclination with the ground horizontal. The vertical reaction has been calculated for the whole range of outrigger arm motion. This will help in selecting the bearing of hydraulic actuator required to meet force requirements.

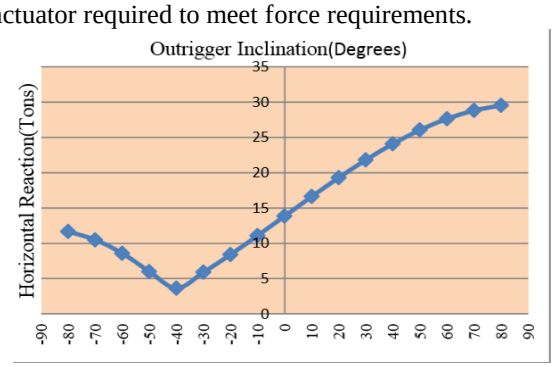

Figure.9. Outrigger inclination Vs Horizontal reaction

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The graph (Figure 11) shows the variation of horizontal reaction at the bearing with the outrigger arm inclination with the ground horizontal. The horizontal reaction has been found out for the whole range of outrigger arm motion from -90 degrees to +90 degrees. From this we can select the bearing of hydraulic actuator required to meet force requirements.

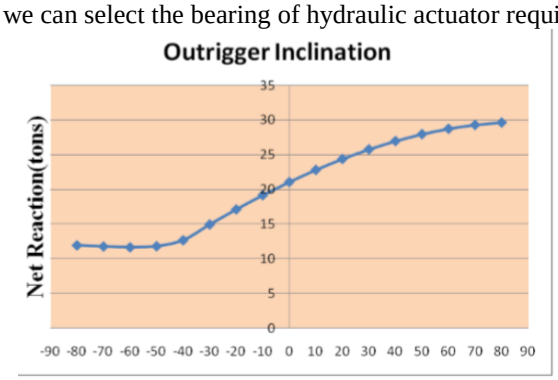

Figure12. Outrigger inclination Vs Net reaction

The Figure12 illustrates the variation of net reaction at the bearing with the outrigger arm inclination with the ground horizontal. The net reaction has been calculated for various positions of outrigger arm motion. This will enable us to select the bearing of hydraulic actuator required to meet force requirements.

IV. CONCLUSION

Slider crank mechanism inversion was selected to derive the outrigger arm mechanism. From the kinematic diagram the DOF are found out. Detailed load analysis was done using static force analysis methods. Relevant equations for static force analysis were generated to compute the forces acting on the stabilizer arm. Mat lab method was used to determine the forces on the outrigger arm for various positions. . The actuator forces, actuator length and the reaction forces were plotted graphically. This method of informal synthesis provides a quick method to configure and synthesize as well as to analyze mechanism of this class.

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