Design and kinematics of a Coal Bunker scraper guide mechanism

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Abstract

The paper discusses the evolution of a robotic mechanism which can closely follow the perimeter walls of a coal bunker. A mechanism, which slides on a track along the perimeter and guides the scraper, is constructed. The robot is designed keeping in mind its rigidity and achieve its functionality. The most desired parameter of this robot is the proximity to the walls when the scraper moves to all altitude levels of the bunker. The mechanism discussed, permits the scraper to be guided along the walls of a rectangular frustum. Design and selection of parts were done by conventional methods. Workspace analysis of the resultant mechanism was done in Matlab to ascertain the reach of the scraper. Kinematic development of the mechanism is discussed in brief. Design criticality of structural members was analysed numerically.

***Keywords*:** Scraping, Mechanism, Workspace, Coal

1. Introduction

A coalbunker is a large storage facility for coal in a power plant. Coal bunker scraping is a routine process of cleaning a coal bunker. Coal from bunker flows to ball mill and subsequently to the pulverizing mill. The continuous flow of coal is necessary for optimal operation of the power plant. Coal is expected to flow by gravity. While this arrangement works in dry coal, scraping becomes necessary process in wet conditions, when coal sticks to the walls. The problem of scraping cannot be carried out effectively by human interference but needs a robotic entrance.

Considerable research and design has been made for a similar application as explained by Dandan et al[1].A review of cleaning techniques including whip type cleaning has been described by Dandan et al[2] in another paper. However, most papers discuss on the lines where the material being handled is in powder form and small quantities[3]. There are numerous other commercial solutions as well[4] with little or no demarcating effect to each other. While most solutions may work to a good extent in circular hoppers[5], the mechanism for a bunker with rectangular frustum Fig. 1 is not explored. This paper discusses the generation of a mechanism and its design to meet these requirements. The mechanism proposed in this paper is built on the functional requirement of heavy payload, rugged construction keeping in tab the requirement of positioning, reach and safety. The mechanism consists of a closed chain mechanism, which guides the scraper to the required position in the bunker. While the scraper has to reach the walls[6], the projection of the scraper can be traced to an imaginary point on a plane on top of the bunker. This is the required point that has to be traced by the mechanism in order to position the scraper to the proximity of walls.

The use of a mechanized scraper reduces industrial risk [7]. While most mechanisms are based on serial manipulation, some are based on parallel manipulation, which can handle a higher payload [8]. In this paper, a 2-DOF manipulator is modelled to position the end effector along the walls of the bunker. This is achieved using a P-R, R-P configuration[9]. The scraper guide trolley adds to it a concatenated effect of the actuator, which gives it two degrees of freedom. The paper discusses the development of the mechanism, the physical and industrial constraints it meets. The workspace of the end effector is of prime importance, as it has to follow a path close to the walls. The given mechanism is most beneficial in case of rectangular cross-section bunker.

2. Development Of Mechanism

The mechanism is a forced closed chain mechanism. Taking inputs from Feng Gao[9], the mechanism follows an R-P'P'R-P configuration Fig 1. The prismatic joint is superimposed on another prismatic joint. The spatial process that mechanism possess is a translational motion by using the rotational and prismatic joints.

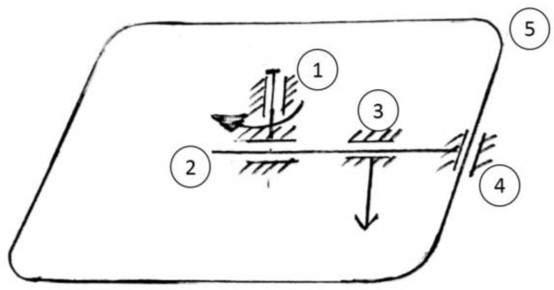

Fig. 1. Kinematic arrangement of the mechanism
1) Rotating axial support 2) Sliding beam 3) End effector 4) Link.4 (trolley) 5) Guide Track

The first rotational joint is fixed to the top surface of the bunker. The type of constraint between links is pin type, allowing one degree of freedom. This is connected to the second link (beam) by a prismatic joint in a perpendicular plane. This joint allows the span of the link to change as per the contour of the guide track. The second link is not directly powered and is dependent on the guide track, hence does not contribute to the degree of freedom. The third link or the sliding link on the second link is the end effector. This part does not form a part of the chain, but is an actuated link on the second link. The second link is directly connected to the fourth link (trolley) by means of a pin joint. The fourth link is resting on a guide track. The trolley is the driven part and gives the tangential motion to the end effector link. This actuator achieves the first degree of freedom. The end effector link-2 itself being an actuated link adds a degree of freedom, hence giving the mechanism a two degree of freedom..

Table. 1. Link and constraints

Link number	Constraint	Degrees of freedom	Links connected
Link-1:Rotating axial support	Pin	1	Base & link-2
Link-2:Sliding beam	Sliding	Dependent	Link1 &Link4
Link 3:End effector	Sliding	1	Link2
Link4:Trolley	Sliding	1	Link2 & Base

As the complete mechanism consists of two actuators responsible for the beam rotation and the end effector motion respectively, leading to 2-DOF translational capability of mechanism. Kinematic arrangement of such kind opens avenues for higher degree of freedom to the mechanism. This is result of the higher pair at the sliding outer end of the mechanism.

3. Design Criticality

The mechanism, an alternate means of a trained coal-cleaning worker in operating inside the confined space, must fulfill the following design requirements. First being the workplace requirement. The mechanism has to be transported to the bunker. In most cases, the bunkers are more than 20metres tall and have minimal approach path to its loading area. Therefore considering this aspect it must have appropriate weight and size, or assembly should be possible at the place. Secondly, the entire equipment must be compact and robust for handling purpose so that it can enter a confined small opening for operation. The mechanism should facilitate reach to every location of the bunker at all the heights. In addition to it, the robot must be able to move inside the silo to scan the entire height from top to bottom, letting the cleaning tools reach every point of the interior surface. The mechanism should hold the end effector during the cleaning process. Maintenance of cleaning tools and supporting equipment at regular intervals should be possible.

Table. 2. Stress Distribution at Different Loading

Position	*Span [m]*	*Load position from track [m]*	*Maximum Stress [Pa]*10^6*
1	3.00	0.5	17.956
2	5.61	0.5	24.550
3	3.00	1	23.219
4	5.61	1	33.880

The actual design of this mechanism includes many components. Hence, discussion on only critical parts is done here. The critical parts were identified. The beam and the joint end at the trolley section are the critical components when subjected to loading conditions. Beam is the primary structural support as well as the main contributor of weight to the mechanism. In addition, the beam has to handle the loads at different spans and different locations of the beam. For facilitating the movement of the prismatic actuator, I-section beam is selected. The MB150 beam has proved to be sufficient for given data. The data containing the extreme and minimum span length and load is given in table 2. The data is for a bunker with plan dimensions of 7-meter breadth and 11-meter length*. The depth of the bunker is 20-meter. The load is taken as 5kN.*The dimensions have been taken from the actual bunker where this mechanism is being implemented*

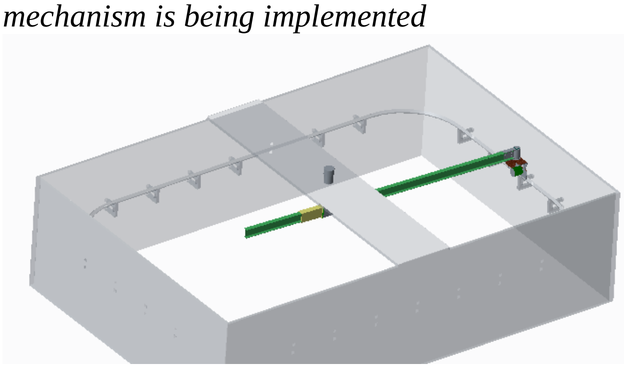

Fig.2 .a. Design of mechanism structure

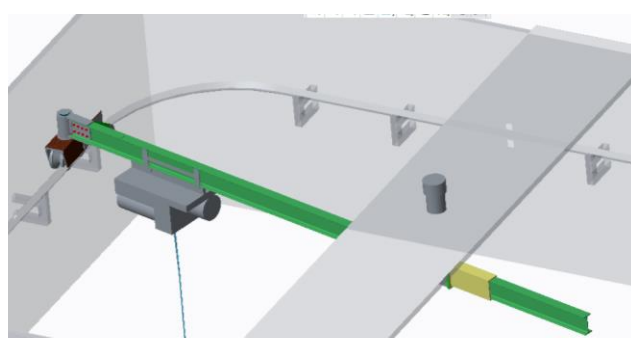

Fig.2 .b. Design of mechanism with end-effector

The, stress generated in the beam is well within the safety factor (Table.2) and will not cause any safety issue for forecasted dynamic loads to the end effector. The load considered on the beam is the consolidated weight of all the apparatus on the end effector to be used for scraping. Also a factor of 1.5 in loading is taken, overseeing the reaction force contained by the end-effector. This service factor has been taken considering the design of scraper mechanism[10]. As seen in Fig.2.a, the beam is a propped beam. The end condition is fixed-sliding at the central bearing and simply supported at the trolley end.

4. Kinematic Workspace Analysis

The mechanism is conceptualized for a locus almost similar to the perimeter of the bunker. In actual case, the locus traced is not as perfect due to the different inclination of link-2 to the guide track at different position. The kinematic workspace analysis is subject to boundary constraints of the bunker as well as the resolution of the servomotor driving the trolley of the mechanism.

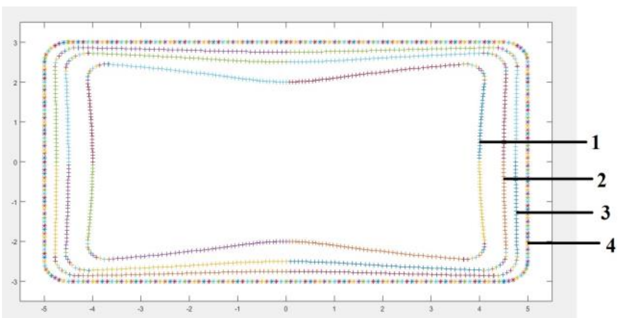

Fig. 3. Locus of end effector for a fixed point on the beam
Position of track is **(4) 0.5meters from wall position of end effector at (1)1m (2)0.5m (3)0.25m**

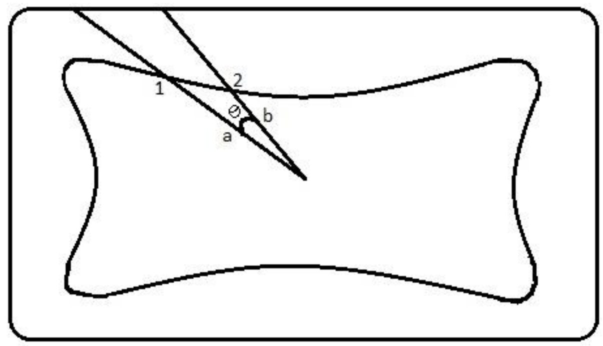

Fig.4. Track profile and the end effector profile generated. Here, **a and b are the initial and final span length, theta is the angle formed**.

The motor generates a dotted near rectangular plot on the guide track. The distance between the dots is governed by the resolution of the motor coupled with the inertia of the system and braking accuracy. In this mechanism, end points of the effector generates co-ordinate data for almost all spatial point in the bunker. Such analysis would generate lot of redundant data regarding workspace[11]. In the current analysis method, three distant points of actual application are taken into consideration. In Fig. 3, the points are at a distance of 0.25m, 0.5m, and 1m respectively. The equation of line joining the track and central bearing was generated and a point at specified distance was taken on that line. For that fixed length, the points were plotted using Matlab as in Fig. 3.

Table.3. End-Effector sliding distance

Position	*Actual Y-coordinate [m]*	*Required Y-coordinate [m]*	*Y displacement*	*Actuation distance [m]*
1	2.35	2	0.35	0.7615
2	2.25	2	0.25	0.3903
3	2	2	0	0
4	2.25	2	0.25	0.3903

The locus of these points shows the co-ordinate of the end effector. Since the required position is parallel to the wall, the locus represents a modified position of the end effector. To achieve the actual position on the beam, the end effector has to move a bit to compensate for the distance. Symmetric points were taken along the trajectory of the end effector. The actual distance from track to the required distance from the track is shown in Table 3.The actuation of the end effector by the correction distances will lead to more precise positioning of it. The following function relates the angle theta generated at the centre by the link to the initial and final pose of the sliding trolley on track. The initial coordinate of pose being x_i, y_i and x_{i+1}, y_{i+1} being the final coordinated of the slider on track.

$$\theta = \cos^{-1}\left(\frac{x_i x_{i+1} + y_i y_{i+1}}{\sqrt{(x_i^2 + y_i^2)(x_{i+1}^2 + y_{i+1}^2)}}\right) \tag{1}$$

Where theta is the angle formed by the two positions (fig. 4). The theta values found from eqn.1. is used to find the motion required by the end effector to keep itself parallel to wall.

5. Conclusion

A robust mechanism with multiple constraints was generated by constrained application of industrial functionality. A rigid mechanism of industrial grade and ease of handling was evolved. The mechanism greatly reduces the human interference in the process of scraping. In addition to that, the continuous operation of this mechanism increases the bunker operational capacity. An end effector base was created to facilitate the planar motion of a point. The mechanism proves to be practically feasible from an industrial, design, assembly and safety point of view.

6. References

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