Lecture Notes in Mechanical Engineering

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Advances in Applied Mechanical Engineering

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Preface

The main aim of the First International Conference on Applied Mechanical Engineering Research (ICAMER 2019) is to bring together all interested academic researchers, scientists, engineers, and technocrats and provide a platform for continuous improvement of mechanical engineering research.

ICAMER 2019 received an overwhelming response with more than 300 full paper submissions. After due and careful scrutiny, about 160 of them have been selected for oral presentation. The papers submitted have been reviewed by experts from renowned institutions, and subsequently, the authors have revised the papers, duly incorporating the suggestions of the reviewers. This has led to significant improvement in the quality of the contributions.

Springer publications have agreed to publish the selected proceedings of the conference in their book series of Lecture Notes in Mechanical Engineering (LNME). This enables fast dissemination of the papers worldwide and increases the scope of visibility for the research contributions of the authors.

This book comprises three parts, viz. thermal, design and production engineering. Each part consists of relevant full papers in the form of chapters. The thermal part consists of chapters on research related to IC engines, CFD, solar energy, automobiles, etc. The design part consists of chapters on computational mechanics, design of mechanisms, composite materials, tribology, and advanced areas like the isogeometric analysis. The production part consists of chapters on machining, new materials, additive manufacturing, unconventional manufacturing, and industrial engineering areas. This book provides a snapshot of the current research in the field of mechanical engineering and hence will serve as valuable reference material for the research community.

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Prof. N. V. Ramana Rao, Director, NIT Warangal, and Prof. P. Bangaru Babu, Head, Department of Mechanical Engineering, have been a constant source of inspiration and support. We deeply acknowledge their contributions. Special thanks to Dr. Vijay Kumar Manupati, Dr. Syed Ismail, and Dr. Karthik Balasubramanian for their prompt efforts in the review process. Contributions by the research scholars from the Department of Mechanical Engineering are praiseworthy.

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We express our sincere thanks to all the deans, registrar, head of the departments, and faculty-in-charges of various units of NIT Warangal for their administrative support in making this effort possible.

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Design and Kinematics of a Coal Bunker Scraper Guide-Mechanism

Bijoy Ramakrishnan, Alex Sherjy Syriac, Chetan Chaudhari, Aditya Shah and S. S. Chiddarwar

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 achieves 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. The kinematic development of the mechanism is discussed in brief. The design criticality of structural members was analyzed numerically.

Keywords Scraping · Mechanism · Workspace · Coal

1 Introduction

A coal bunker 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 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 a 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 have 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 and patents discuss the lines where the material being handled is in powder form and small quantities [3]. There are numerous other commercial solutions as well

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[4] with little or no demarcating effect on each other. While most solutions may work to a good extent in circular Hoppers [5], the mechanism for a bunker with rectangular frustum 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 as well. 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 the 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 modeled 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 the case of a rectangular cross-sectional 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 possesses is a translational motion by using the rotational and prismatic joints.

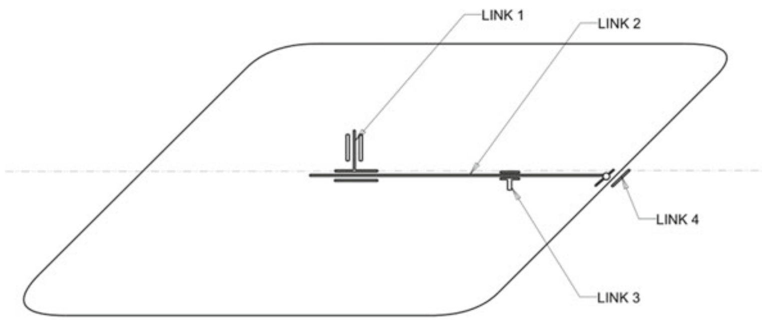

Fig. 1 Kinematic arrangement of the mechanism

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 and 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.

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. The kinematic arrangement of such kind opens avenues for a higher degree of freedom to the mechanism which is uncalled for. This is the result of the higher pair at the sliding outer end of the mechanism. It can be constrained by keeping the tolerance of contacting parts in check.

3 Design Criticality

The mechanism 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 20 m tall and have minimal approach paths to their 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 purposes 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, allowing the cleaning tools to 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 1).

Table 1 Link and constraints

Link number	Constraint	Degrees of freedom	Links connected
Link-1: Rotating axial support	Pin	1	Base and link-2
Link-2: Sliding beam	Sliding	Dependent	Link-1 and Link-4
Link-3: End effector	Sliding	1	Link-2
Link-4: Trolley	Sliding	1	Link-2 and base

The actual design of this mechanism includes many components. Hence, discussion on only critical parts is done here. 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. For practicality of the mechanism, standard available beam sizes were chosen from data book and FEM analysis [10, 11] was done on the most optimal beam size. The MB150 beam has proved to be sufficient for given data. The initial guess on a range of beam size is based on the bending moment equation. The beam is expected to operate between a range of values for the given dimensions of bunker. This was calculated as 3-m and 5.61-m span, respectively. The data containing the extreme and minimum span length is given in Table 2 as well. The calculation for the beam taken is a similar approach as the one taken by Leszek Sowa [10]. The data is for a bunker with plan dimensions of 7-m breadth and 11-m length. The depth of the bunker is 20-m. The load is taken as 5 kN for all analysis purposes. The load taken is the consolidated weight of the mechanism and driving support. It is inclusive of service factors and safety factors. The dimensions have been taken from the actual bunker where this mechanism is being implemented.

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 experienced by the end effector. This service factor has been taken considering the design of scraper mechanism [11]. As seen in Fig. 2a, the beam is a propped beam. The end condition is fixed sliding at the central bearing and simply supported at the trolley end.

The trolley end of the mechanism (link-3) is also a critical part of the working. It was observed from stress analysis that a stress concentration zone forms at trolley pin joint. The stress was reduced by adding supports as required and increasing the dimension. Design details are limited to the identification of critical parts and concluded here to reduce trivial calculations.

Table 2 Stress distribution at different loading

Position	Span (m)	Load position from track (m)	Maximum Stress (MPa)
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

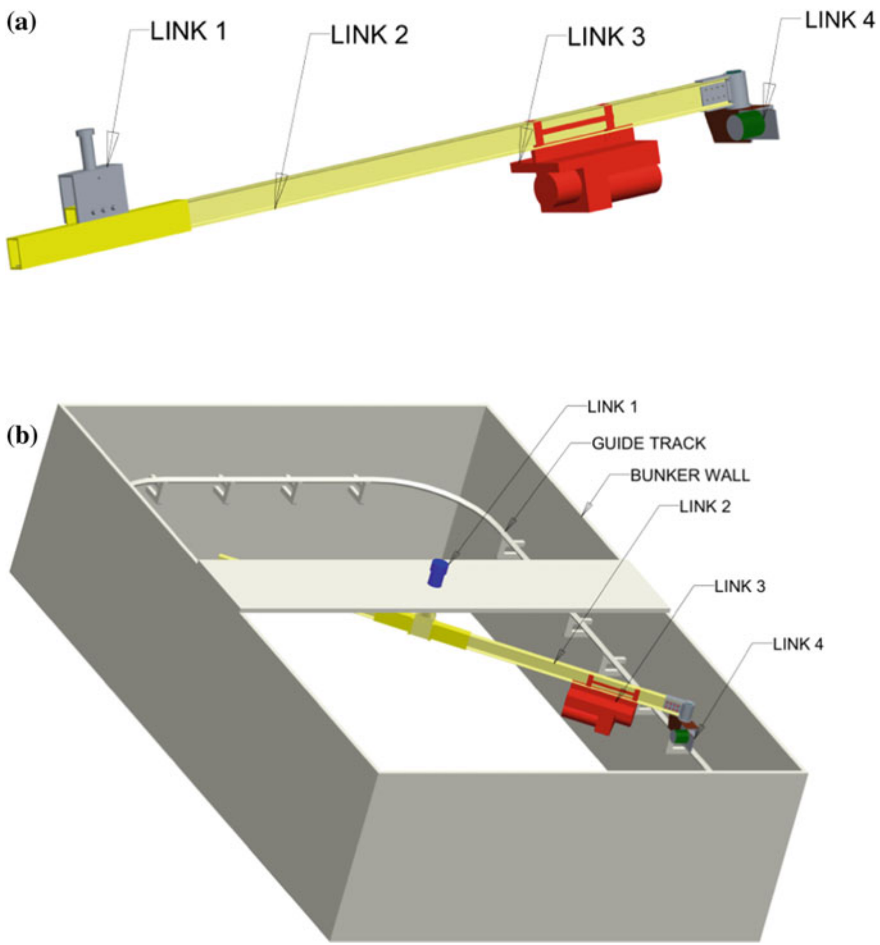

Fig. 2 **a** Design of mechanism structure. **b** Design of mechanism with end effector in the bunker

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 positions. 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.

The motor generates a dotted locus near the 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, endpoints of the effector generate coordinate data for almost all spatial points in the bunker. Such analysis would generate a lot of redundant data regarding workspace [12].

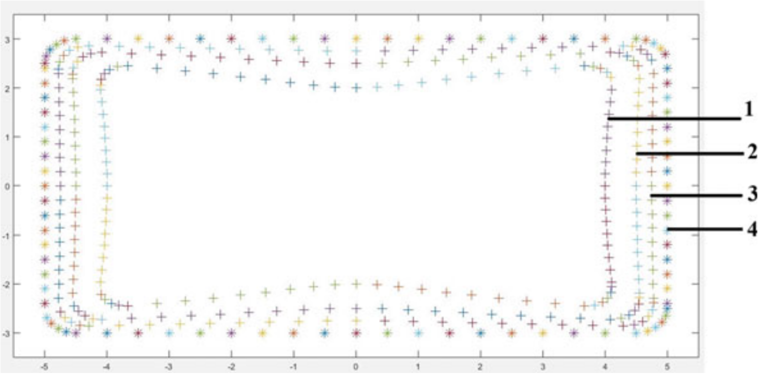

Fig. 3 Locus of end effector for a fixed point on the beam position of track is (4) 0.5 m from wall position of end effector at (1) 1 m (2) 0.5 m (3) 0.25 m

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 0.25 m, 0.5 m, and 1 m, 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.

The locus of these points shows the coordinate 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 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 center by the link to the initial and final pose of the sliding trolley on track. The initial coordinate of the pose being x_i, y_i, and x_{i+1}, y_{i+1} is 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 Eq. 1 are used to find the motion required by the end effector to keep itself parallel to wall.

5 Conclusion

Scraping is a necessary part of a coal bunker. Coal bunker has existed for centuries and technology regarding them has evolved. The current mechanism has evolved based on the improvement in support systems which allow much precise motion

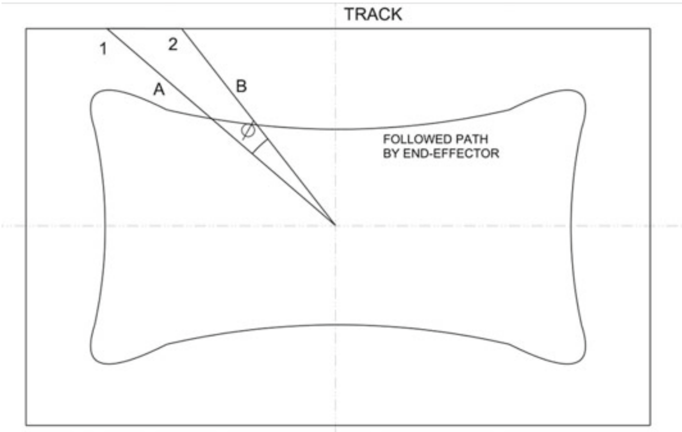

Fig. 4 Track profile and the end effector profile generated. Here, A and B are the initial and final link length for position 1 and 2, respectively; ϕ is the angle formed between them

of the arm. A robust mechanism with multiple constraints was generated by the 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.

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