

Single Axis Solar Tracker for Parabolic Trough Cylindrical Concentrator

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ABSTRACT: An attempt is made to design and construct a single axis tracking system for the line focused concentrator. Equal arm balance structure is proposed and analyzed for the number of clear sunny days to track the parabolic trough system towards the motion of the sun. The system is made with the local available materials and can be used for small portable system with the less maintenance. The system is cost, effective and economical so that the technology can be extended to the parabolic trough system of large aperture area.

KEYWORDS: single axis solar tracker, parabolic trough system, equal arm balance

I.INTRODUCTION

Solar tracker is an indispensable increases the thermodynamic efficacy of the parabolic trough system by orienting the collector towards the motion of the sun. The tracker is made to operate manually as well as automatically using discrete elements such as LDR, photodiodes. In such tracker, the sensors used are highly sensitive for weather condition such as temperature and humidity. Researchers have made sincere efforts to design and fabricate an efficient tracking system and succeeded.

FabienneSallaberry *et al.* (2015) have proposed a procedure to characterize the accuracy of the single axis solar tracker. Positioning angle error of a parabolic trough collector is estimated directly and the angular tracking error of 0.4° with average optical loss of 0.317% is found. A single axis three position (1A-3P) low-cost sun tracker is tested by the Bin-Juine Huang *et al.* (2013) for south, southeast and south west orientation. It is observed that the energy loss of 1A-3P PV system due to misalignment of South is negligible and energy loss of 4.42-6.82% and 4.31-6.79% for southeast and southwest orientations.

Chin *et al.* (2011) is designed, modelled and tested a active single axis solar tracker. The tracker consists of LDR sensors positioned on the surface of the photovoltaic panel. The tracker is modelled using the MATLAB and the simulation results are in good agreement with the experimental results. Roberto Bruno *et al.* (2015) is designed with new single-tracking PV modules with lesser width and weight functioning with low power actuators and two control strategies for the rotation angle of the modules with respect to the horizontal tilted-axis is tested. The problem of self-shading of the modules are highlighted for optimizing the production of the electrical energy. BouzianeKhadidja *et al.* (2014) has implemented a solar tracker system for studying tilt angle to the PV conversion panels in Ouargla city. It is revealed that the modules with the tracking system with the tilt angle have given the yield of 15 to 35% higher than the fixed PV modules. Tina and Scandura (2012) have conducted a study with the photovoltaic systems consisting of two PVSSs, a storage system and an inverter operating both in the island and grid-connected modes. The first PV is provided with the single axis tracking system facing south tilted 30° and the second PV with dual axis tracking system consisting of a concentrator at the flat mirrors. It is found that the system is cost effective for a low-concentration system. Zafrullah Jagoo (2013) is undergone a review for various types of solar trackers and inferred that dual-axis solar tracker is the most efficient and effective tracking system. The system works with the principle based on the

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microcontroller computing real-time altitude and azimuth of the sun. Codruta Jaliuet *al.* (2013) have designed a new actuator variant for the tracking system with the DC/AC motor ensuring high transmission ratio and the study revealed that the design complication and losses due to the friction and it has been reduced. Dehelean and Dehelean (2011) have proposed a mechanism for the implementation of the reflection function to orient the heliostat set of mirrors that track the sun. The results of the study indicated the effectiveness of the heliostat field for the production of electricity. Ahmad Parvaresh *et al.* (2011) have attempted to design a tracking system based on azimuth and elevation angle of the sun. The performance of the tracking system has been compared with the tracking system based on the optical sensor. It is found that the efficiency is higher than the system with the optical sensors.

In the present study, an attempt has been made to design a new tracking system with the equal arm balance method depending on the mass of the parabolic trough system. Theoretical calculations have been done and compared with the experimental results of the system during the tracking towards the motion of the sun.

II. MATERIALS AND METHODS

II. 1Parabolic trough

Parabolic trough system of 2m length is fabricated with the mild steel and the reflector is pasted on the curved surface of the trough. The trough is mounted on a supporting stand provided with the axle, bearing and spacer to undergo the spontaneous rotation at any instant of time. The focal line of the trough system is at 0.135m from the centre of the curved base and receiver made of copper tube is mounted on the focal line. The aperture area of the parabolic trough is 1m^2 . Pressure head has been used to flow the heat transfer fluid through the copper tube to provide the required pressure. The tracking mechanism for the trough has been designed using equal arm balance method and separate water tank is used to circulate water for tracking. Fig. 1 represents the schematic diagram of the trough system and photograph of the proposed system is depicted in the Fig. 2. Necessary hardware accessories used for the fabrication of parabolic trough system has been depicted in the Fig. 3.

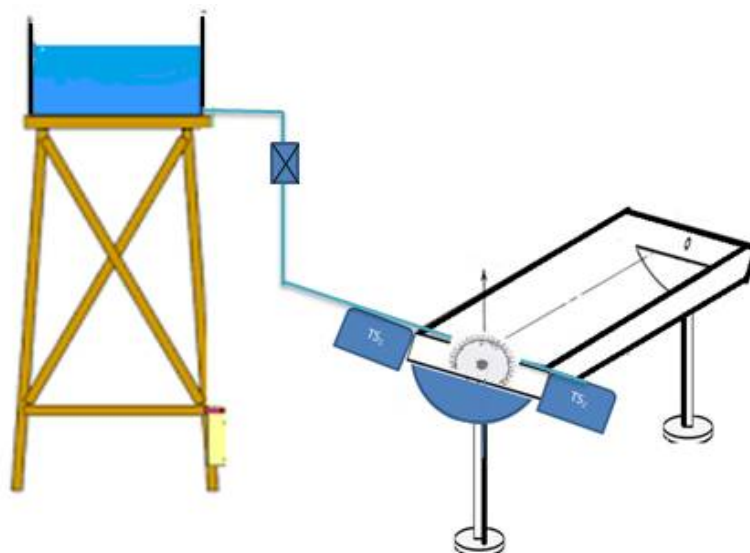


Fig. 1 Schematic diagram of the proposed parabolic trough system with the tracker

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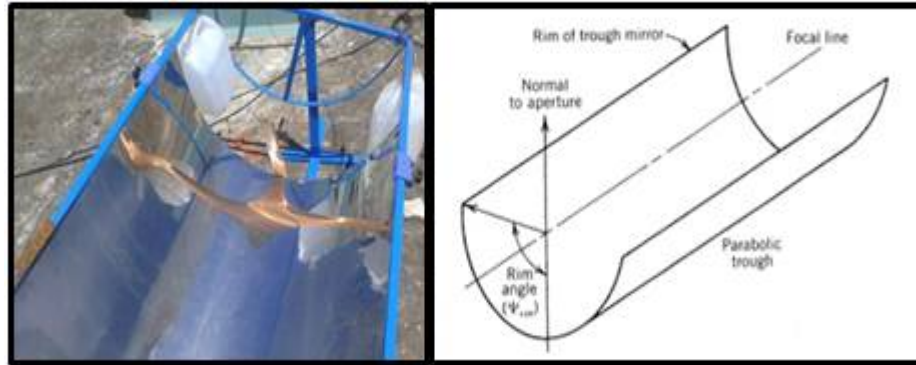


Fig. 2 Photograph and Schematic diagram of the proposed parabolic trough system



Fig. 3 Hardware accessories for the fabrication of parabolic trough system

II.2 Construction of equal arm balance structure

Equal arm balance structure has been made using the water containers (TS1 & TS2) fixed at each corner of the edge of the trough system and water has been flown into the container from storage tank mounted at certain height above the trough system to acquire required pressure through a governor. Gauging tracking orientation has been carried out using a geometrical protector along with the equal arm balance structure. Geometrical protector is used to orient the trough system in a desired initial position of the trough system. Fig. 4 shows the photograph of the trough system with the initial adjustments made with the help of protector and water mass in the container on both the sides of the edge of the trough system. Spirit level is utilized to keep the trough firmly in the horizontal plane. Fig. 5 and Fig. 6 show the photograph of the 2m and 1m trough system and Table. 1 represents the specifications of the proposed system.

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Fig. 4 Photograph of the trough system with the initial adjustment



Fig. 5 Photograph of 2m Parabolic Trough with the Tracking System
Fig. 6 Photograph of 1m Parabolic Trough with the Tracking System

Table. 1 Design specifications of 1m and 2m parabolic trough system

Description	Material	Specification m		Weight kg	
		1 m	2m	1m	2 m
Reflector (ss)	SS Sheet (2mm)	1*1	2*1	1.568	3.136
Rectangular frame(Ms)	MS Square Pipe	1*0.64	2*0.64	5.115	6.015
Curvature	MS Flat Plate (thick 7mm)	2	3	1.008	1.512
Bolt nut connector	Iron steel			0.112	0.612
Axle (17 mm)	Ms polish rod	0.2	0.2	0.7055	0.7055
Parabolic Trough		1	2	8.5085	11.6205
Focal line		0.135		-	-

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III. RESULTS AND DISCUSSION

III.1 Experimental Work

Experiments have been done from 9am to 4 pm with the parabolic trough system with the proposed tracking mechanism in the Department of Physics, Karpagam University, Coimbatore, Tamilnadu, India. Initially, the 1m parabolic trough is oriented towards east at 9 am with the mass of water about 2.1834 kg in the eastern side tank TS1. It is observed that, for the rotation of 1°/4 minutes tilt has been obtained with the addition of 0.04852 kg in the western side tank (TS2). Similarly, water mass of about 0.065475 kg is required for 2m parabolic trough system.

Water flow rate in the western side tank has been controlled by using the speed governor to control the rotatory motion of the trough system. To verify theoretically, a simple mathematical formula has been derived.

IV MATHEMATICAL EXPRESSION

III.2 Mass conversion equation

Total mass of the entire body is distributed through the radius of the collector its shape is semi-circle.

Total angle to be tilted for east to west is π

$$\text{Mass required for tilting an angle of } 1^\circ = \frac{\text{Total mass of the collector}}{180} \quad (1)$$

In case additional mass is prerequisite to be calculated by

$$\text{Mass required for tilting an angle of } 1^\circ = \frac{\text{Total mass of the collector}}{180} + \frac{\text{added mass}}{180} \quad (2)$$

To find weight to keep the trough in a balanced position,

Total weight of the trough $M_T = 11.6205$ kg

To maintain the trough in a balanced position, required weight of water in both eastern and western water container is found to be $L=R (M_c) = 5.9175$ kg

Mass of water required in western side container per unit degree twist is 0.06575 kg/s (M_a) as the angle to be swept at 12 noon is 90° and α is the required degree to be tilted. Thus the total mass of water is found to be

$$M_T = (M_C + M_a \alpha) + (M_C - M_a \alpha) \quad (3)$$

Further, the mechanism can be used to the system with different weight and additional weight is incorporated as M_{added} and can be written in the equation for tilt as

$$\alpha = \pi - \frac{M_T - M_{\text{added}}}{M_a} \quad (4)$$

For the above expression, the plane of the trough is perpendicular to the sun's ray and satisfies the balanced condition as

$$\tan 180^\circ \left(\frac{\tan \pi + \tan \alpha}{1 - \tan \pi \tan \alpha} \right) - \tan \alpha = \tan 180^\circ \left(\frac{\tan \pi + \tan \alpha}{1 + \tan \pi \tan \alpha} \right) + \tan \alpha \quad (5)$$

$$\tan(\pi + \alpha) + \tan(\pi - \alpha) = 0$$

Based on the Eqs. 4 and 5, Figs. 7 and 8 represents the angle for tilt for twist angle α and it is clear from the figures that, at any desired position, sun's rays is always perpendicular to the plane of the trough system.

Based on the conversion equation, the theoretical value has been compared with the experimental value and found to be agreed with each other with the minimum error. Table. 3 represents the theoretical and experimental values of water added in the western side of the trough system for 2m trough. Fig. 9 represents the single axis tracking mechanism focal point (f) for both 1m and 2m parabolic trough systems.

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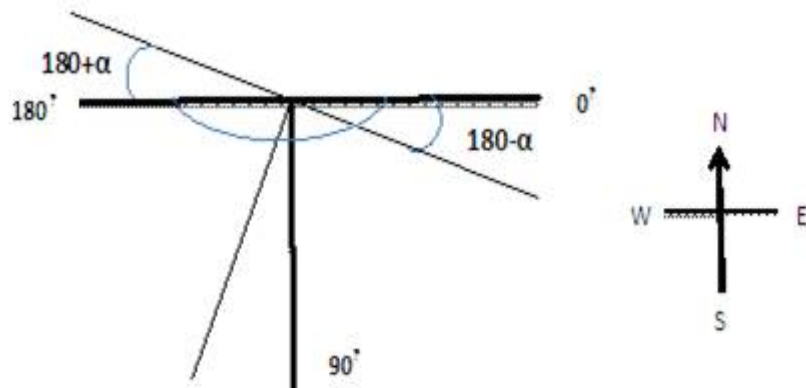


Fig. 7 Desired position of the trough towards west perpendicular to sun's rays

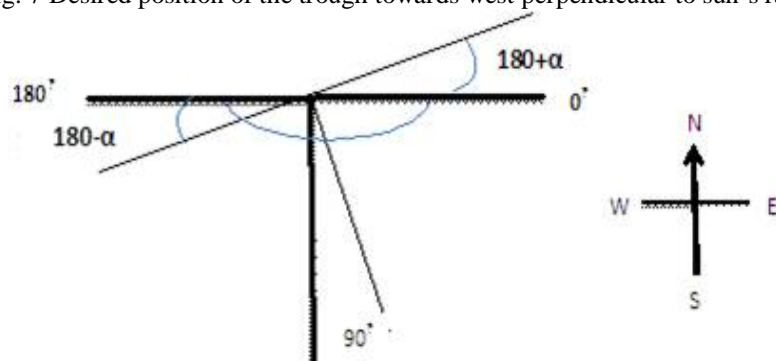


Fig. 8 Desired position of the trough towards east perpendicular to sun's rays



Fig. 9 Single axis tracking system focal point for both 1m and 2m parabolic system

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Table. 2 Experimental and theoretical values of mass of water added per second in western side container,

Degree of tilt	Theoretical value of weight of drop of water added to tilt the trough by 1°	Experimental value of weight of drop of water added to tilt the trough by 1°	Degree of tilt	Theoretical value of weight of drop of water added to tilt the trough by 1°	Experimental value of weight of drop of water added to tilt the trough by 1°
1	0.064558333	0.06575	39	2.517774987	2.56425
2	0.129116666	0.1315	40	2.58233332	2.63
3	0.193674999	0.19725	41	2.646891653	2.69575
4	0.258233332	0.263	42	2.711449986	2.7615
5	0.322791665	0.32875	43	2.776008319	2.82725
6	0.387349998	0.3945	44	2.840566652	2.893
7	0.451908331	0.46025	45	2.905124985	2.95875
8	0.516466664	0.526	46	2.969683318	3.0245
9	0.581024997	0.59175	47	3.034241651	3.09025
10	0.64558333	0.6575	48	3.098799984	3.156
11	0.710141663	0.72325	49	3.163358317	3.22175
12	0.774699996	0.789	50	3.22791665	3.2875
13	0.839258329	0.85475	51	3.292474983	3.35325
14	0.903816662	0.9205	52	3.357033316	3.419
15	0.968374995	0.98625	53	3.421591649	3.48475
16	1.032933328	1.052	54	3.486149982	3.5505
17	1.097491661	1.11775	55	3.550708315	3.61625
18	1.162049994	1.1835	56	3.615266648	3.682
19	1.226608327	1.24925	57	3.679824981	3.74775
20	1.29116666	1.315	58	3.744383314	3.8135
21	1.355724993	1.38075	59	3.808941647	3.87925
22	1.420283326	1.4465	60	3.87349998	3.945
23	1.484841659	1.51225	61	3.938058313	4.01075
24	1.549399992	1.578	62	4.002616646	4.0765
25	1.613958325	1.64375	63	4.067174979	4.14225
26	1.678516658	1.7095	64	4.131733312	4.208
27	1.743074991	1.77525	65	4.196291645	4.27375
28	1.807633324	1.841	66	4.260849978	4.3395
29	1.872191657	1.90675	67	4.325408311	4.40525
30	1.93674999	1.9725	68	4.389966644	4.471
31	2.001308323	2.03825	69	4.454524977	4.53675
32	2.065866656	2.104	70	4.51908331	4.6025
33	2.130424989	2.16975	71	4.583641643	4.66825
34	2.194983322	2.2355	72	4.648199976	4.734
35	2.259541655	2.30125	73	4.712758309	4.79975
36	2.324099988	2.367	74	4.777316642	4.8655
37	2.388658321	2.43275	75	4.841874975	4.93125
38	2.453216654	2.4985	76	4.906433308	4.997

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Degree of tilt	Theoretical value of weight of drop of water added to tilt the trough by 1°	Experimental value of weight of drop of water added to tilt the trough by 1°	Degree of tilt	Theoretical value of weight of drop of water added to tilt the trough by 1°	Experimental value of weight of drop of water added to tilt the trough by 1°
77	4.970991641	5.06275	121	7.811558293	7.95575
78	5.035549974	5.1285	122	7.876116626	8.0215
79	5.100108307	5.19425	123	7.940674959	8.08725
80	5.16466664	5.26	124	8.005233292	8.153
81	5.229224973	5.32575	125	8.069791625	8.21875
82	5.293783306	5.3915	126	8.134349958	8.2845
83	5.358341639	5.45725	127	8.198908291	8.35025
84	5.422899972	5.523	128	8.263466624	8.416
85	5.487458305	5.58875	129	8.328024957	8.48175
86	5.552016638	5.6545	130	8.39258329	8.5475
87	5.616574971	5.72025	131	8.457141623	8.61325
88	5.681133304	5.786	132	8.521699956	8.679
89	5.745691637	5.85175	133	8.586258289	8.74475
90	5.81024997	5.9175	134	8.650816622	8.8105
91	5.874808303	5.98325	135	8.715374955	8.87625
92	5.939366636	6.049	136	8.779933288	8.942
93	6.003924969	6.11475	137	8.844491621	9.00775
94	6.068483302	6.1805	138	8.909049954	9.0735
95	6.133041635	6.24625	139	8.973608287	9.13925
96	6.197599968	6.312	140	9.03816662	9.205
97	6.262158301	6.37775	141	9.102724953	9.27075
98	6.326716634	6.4435	142	9.167283286	9.3365
99	6.391274967	6.50925	143	9.231841619	9.40225
100	6.4558333	6.575	144	9.296399952	9.468
101	6.520391633	6.64075	145	9.360958285	9.53375
102	6.584949966	6.7065	146	9.425516618	9.5995
103	6.649508299	6.77225	147	9.490074951	9.66525
104	6.714066632	6.838	148	9.554633284	9.731
105	6.778624965	6.90375	149	9.619191617	9.79675
106	6.843183298	6.9695	150	9.68374995	9.8625
107	6.907741631	7.03525	151	9.748308283	9.92825
108	6.972299964	7.101	152	9.812866616	9.994
109	7.036858297	7.16675	153	9.877424949	10.05975
110	7.10141663	7.2325	154	9.941983282	10.1255
111	7.165974963	7.29825	155	10.00654162	10.19125
112	7.230533296	7.364	156	10.07109995	10.257
113	7.295091629	7.42975	157	10.13565828	10.32275
114	7.359649962	7.4955	158	10.20021661	10.3885
115	7.424208295	7.56125	159	10.26477495	10.45425
116	7.488766628	7.627	160	10.32933328	10.52

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Degree of tilt	Theoretical value of weight of drop of water added to tilt the trough by 1°	Experimental value of weight of drop of water added to tilt the trough by 1°	Degree of tilt	Theoretical value of weight of drop of water added to tilt the trough by 1°	Experimental value of weight of drop of water added to tilt the trough by 1°
161	10.39389161	10.58575	171	11.03947494	11.24325
162	10.45844995	10.6515	172	11.10403328	11.309
163	10.52300828	10.71725	173	11.16859161	11.37475
164	10.58756661	10.783	174	11.23314994	11.4405
165	10.65212495	10.84875	175	11.29770828	11.50625
166	10.71668328	10.9145	176	11.36226661	11.572
167	10.78124161	10.98025	177	11.42682494	11.63775
168	10.84579994	11.046	178	11.49138327	11.7035
169	10.91035828	11.11175	179	11.55594161	11.76925
170	10.97491661	11.1775	180	11.62049994	11.835

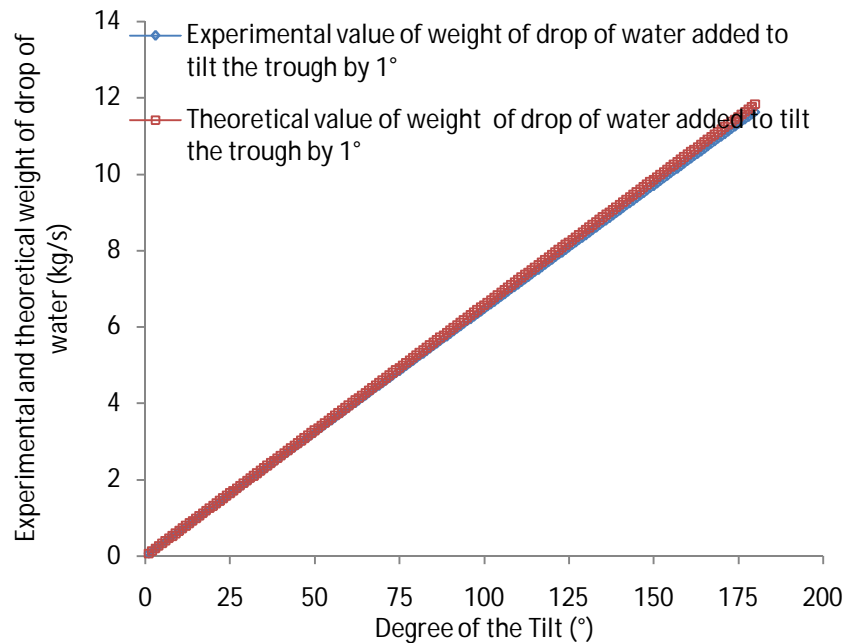


Fig. 10 Experimental and theoretical value of weight of drop of water with respect to that of degree of tilt

Fig. 10 shows the theoretical and experimental values of the weight of drop of the water to be added in a second to track the trough system towards the motion of the sun. From the graph it is observed that the weight of a drop of water increases with the increase of tilt angle and has linear variation. Since the trough has been tracked towards the motion of the sun using arm balance method, it can be extended to the system with large weight and found to be better for the proposed system with least error.

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IV.CONCLUSION

The following conclusions have been drawn from the experiment and are

- (i) The tracking mechanism is based on weight of the trough and can be extended to any trough system.
- (ii) Results of the theoretical calculations are in close agreement with the experimental observations
- (iii) The tracker always maintained the normal position of the aperture of the trough with respect to the solar beam.
- (iv) The proposed tracker has been extensively utilized for both 1m and 2m trough system respectively
- (v) The tracker is suitable for both summer and winter seasons accurately as it is independent of solar radiation intensity.
- (vi) No external power is needed for the functioning of the tracking system.
- (vii) Construction of the system is simple with locally available materials.

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