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Experimental Analysis of Geneva Mechanism for Bottle Washing

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Abstract
This study evaluates the performance of Geneva Mechanism as applied to bottle washing in a typical Beverage or Brewery Industry. A test rig was designed, fabricated and employed for the performance evaluation. The rig operates on the intermittent rotary motion from a four slot external Geneva Mechanism and requires manual loading and unloading of bottles. The bottles are loaded on subsequent indexing part of the rotating table and are washed one after another. Experiments were carried out on the rig by varying speeds and monitoring the cycle time, washing time and indexing time. The speed ranged from 6rpm to 20rpm. The cycle time obtained for selected speeds was between 10.639 seconds and 38.060 seconds, the washing time was between 2.434 seconds and 7.844 seconds and the indexing time was between 0.078 seconds and 1.772 seconds. The maximum pin-slot contact force for selected speeds was between 16N and 29N. The graphs plotted for time taken and number of bottles washed at selected speeds were all linear functions while the graphs plotted by varying other parameters such as speed, maximum pin-slot contact force, cycle time, washing time and indexing were represented by third order polynomial functions of differing coefficients and constants. The times taken to wash eight bottles for all the speeds were 28.922, 35.914, 49.62, 78.414 and 105.372 seconds. The analysis of the results collected from the experimentation gave washing efficiency for the system in the range of 81.57% and 96.89% with the highest value obtained at 19rpm. This work presents a practical application of Geneva mechanism for worktable indexing and bottle washing.
Keywords: Geneva Mechanism, Cycle Time, Bottle Washing, Productivity, Indexing Time, Speed, Rotating Table.

1. Introduction

Geneva mechanism is a simple and widely used timing mechanism that provides intermittent motion from a continuously rotating input. It consists of a rotating drive wheel (Driver) with a pin that reaches into a slot of the driven wheel (Geneva wheel) advancing it by one step (Ejeogo, 2014).

Glass bottles are still being reused widely by beer and soft drink companies. The reuse of bottles in the production process entails a thorough cleaning of these returnable bottles before refilling. Bottles come in from the trade in every condition and degree of cleanliness or dirtiness. Some may contain heterotrophic and other air borne bacteria, a little yeast, others carbolic, paraffin or medicine, others dust. For this reason, the washing cycle must be stringent enough to eliminate any possible contaminants.

In Nigeria, growth in number and capacity of food manufacturing plants is constantly increasing. Some small scale and local beverage drink manufacturers wash bottles manually before reuse and cannot afford most of the bottle washing equipment in the market. This gave rise to the need to design and develop an affordable bottle washing machine.

(Hasty Et al, 1966) defined the wheel geometry and developed the relationship between this geometry and the wheel inertia, the maximum pin load, the contact stress and the inertial wheel stresses. (Jung-Fa , 2014) proposed a comprehensive method for the design of Geneva indexing mechanism with curved slots. He fabricated a Geneva mechanism to demonstrate the feasibility of the proposed method. (Meyer, 1973) conducted a mathematical analysis of Geneva mechanism as a timing device. The idea was to determine if the Geneva mechanism will attain a terminal velocity and if so how much time is required to reach this velocity. His study indicated that the Geneva mechanism does reach a terminal velocity and consequently can be used as a timing device.

2. Materials and Methods

2.1 Test Rig Assembly

The test rig assembly consist of mounting and bolting the bearings on the framework with bolts and nuts, mounting the shafts through the bearing bores and tightening the bearing screws, mounting the Geneva mechanism on the shafts, mounting the driven and drive pulleys on the drive shaft and motor shaft respectively, mounting and bolting the electric motor to its sitting and on its base on the right side of the framework. The water tank was then mounted on its frame, the water pump mounted on its base under the water tank. The flow pipe, pipe fittings, solenoid valve and nozzle were connected in a plumbing work. Union adapters, nipple connectors, elbows and T-pipe joints were used in extending the pipe to required horizontal and vertical lengths.

All the pipe connections were threaded design types. These pipes were fixed using pipe wrenches and plumber's Teflon fibre to prevent leakages. The pipes used were galvanized steel pipes of internal diameter 16mm and 20mm external diameter. The lower chamber cover was then mounted and bolted to the framework, the water collector was mounted inside the chamber lower cover on its sitting, and the limit switch was mounted and bolted to its sitting on the left side of the lower chamber cover. The table with the bottle holders fitted in position were then mounted and keyed to the driver shaft and the upper chamber cover was then mounted in position on top of the lower cover. The control panel was mounted on its stand on the left side of the chamber. Electrical terminals from the solenoid valve, limit switch, water pump, industrial switch and electric motor were connected to the control panel as designed in the electrical circuit. At this stage, the water tank was filled with water and four Amstel malt bottles placed in an inverted position in the bottle holders for a test run of the test rig, in order to identify leakages and other trouble shooting signs from the electrically operated accessories. Minor leakages were taken care of by using plumber's Teflon fibre and tightening the joints using pipe wrenches while arc welding was employed for major leakages. All electrical connections were rechecked and certified for trouble free operation (Figure 1).

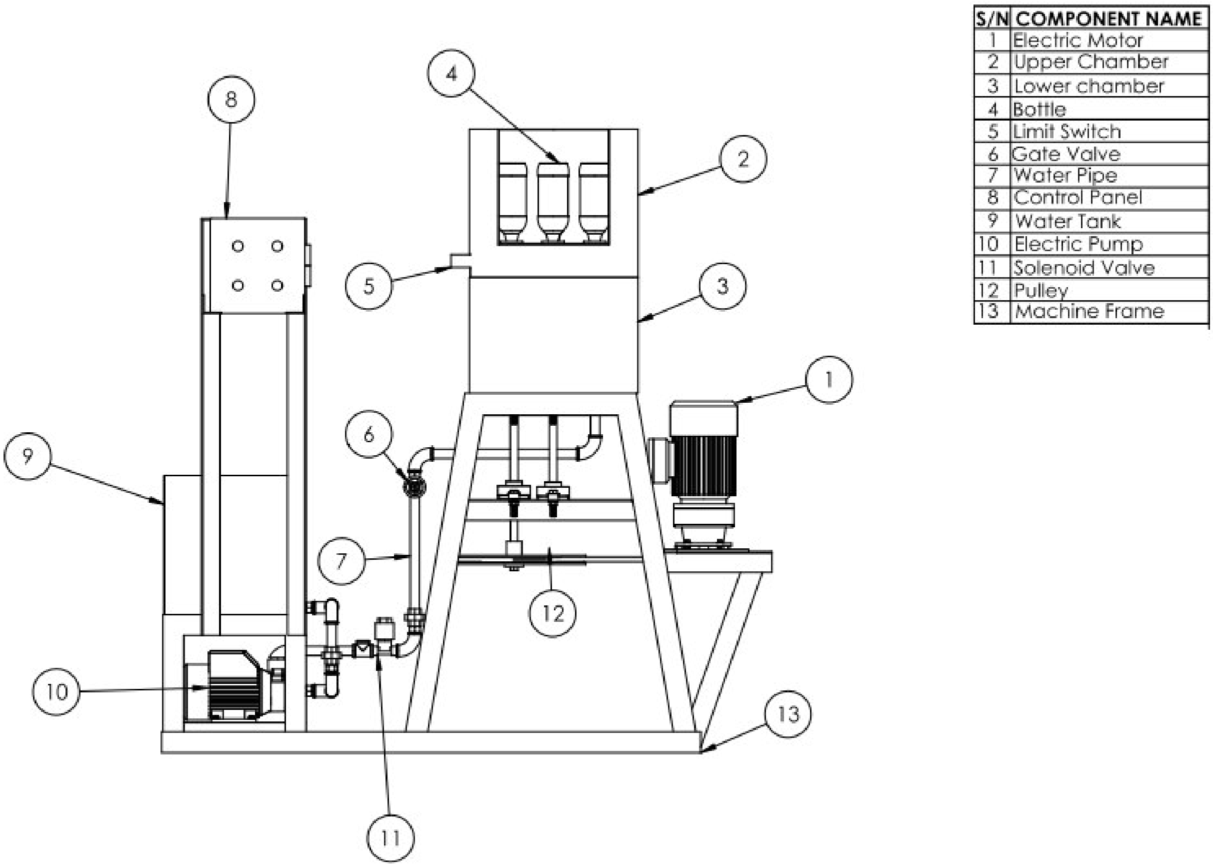

Figure 1. Test Rig Assembly (front view)

2.2 Experimental Methods

The experimental methods consists of the determination of maximum pin-slot contact force, cycle time, indexing time and washing time of the test rig at different selected speeds.

2.2.1Maximum Pin-slot Contact force

SolidWorks 2010 software was used to design the test rig and animate the drive mechanism of the test rig at 6rpm, 8rpm, 12rpm, 16rpm and 20rpm. The pin-slot contact force was calculated and a plot of pin-slot contact force against Driver cycle time at each selected speed generated using the software. The Maximum pin-slot contact force was taken from the graphs and recorded.

2.2.2 Cycle time, Indexing time and Washing time

For one complete cycle of the driver, the table travels through 90^0. Thus, one complete cycle of the table is equal to driver cycle time multiplied by four (4). The dwell time of the Geneva wheel is the washing time of the test rig. The Driver cycle time, indexing time and washing time of the rig were calculated using equations (1) to (3)

(Groover, 2009) and the table cycle time calculated from the driver cycle time. The test rig cycle time, indexing time and washing time were verified using a stopwatch.

Five readings of the cycle time, indexing time and washing time of the test rig were carefully measured and recorded at selected speeds using a handheld digital stopwatch. The average of each set of time were calculated and recorded. Speed change was achieved via the use of pulleys with selected diameters. These ranged from 117.5mm to 391.667mm and the corresponding speeds obtained were 6 to 20rpm ($\pm 1\ rpm$). These speeds were verified using a speed measuring tachometer (model: ATH6, Lucas Industrial Measurement)

$$T_c = \frac{1}{N} \quad (1)$$

Where T_c= cycle time, min

N = rotational speed of driver, rev/min.

$$T_s = \frac{(180+2\beta_0)}{360N} \quad (2)$$

where T_s = Dwell time, ,min

$2\beta_0$ = angle between adjacent slots of the Geneva wheel, degrees

$$T_r = \frac{(180-2\beta_0)}{360N} \quad (3)$$

Where T_r = indexing time, min and other terms are defined above.

3. Results and Discussions

The maximum pin-slot contact force at different selected speeds is shown in the table (1) below.

3.1.1 Results for Maximum Pin-slot Contact force

Table 1: Animation results

S/No	Speed (rpm)	Max. Pin slot contact force(N)
1	6	16
2	8	17
3	12	22
4	16	25
5	20	29

3.1.2 Results for speed verification using a Tachometer

The selected speeds to be used in the experiment were verified using a tachometer (model: ATH6, Lucas Industrial Measurements). The result is shown in the table (2) below. The pulley speeds when verified with the tachometer were found to be very close to expected selected speeds with negligible difference.

Table 2: Pulley Diameter, Calculated speed and Tachometer readings.

S/N	Diameter (mm)	Calculated Speed (rpm)	Tachometer Reading (rpm)
1	391.667	6	5
2	293.75	8	7
3	195.833	12	12
4	146.875	16	15
5	117.5	20	19

3.1.3 Results of Cycle time, Indexing time and washing time verification using a stopwatch

The cycle time, indexing time and washing time of the test rig were verified using a handheld digital stopwatch. The result is shown in the table (3) below. The cycle time, washing time and indexing time of the test rig when verified with the stopwatch were found to be very close to expected calculated values with negligible differences of $\pm 2 seconds, \pm 0.344\ seconds\ and\ \pm\ 0.7475\ seconds$ respectively.

Table 3: Verification of Cycle time

S/N	Speed (Rpm)	Driver Cycle time (Secs)	Cycle Time (Secs)	Cycle Time (Stopwatch Reading)
1	6	10.00	40.00	38.060
2	8	7.50	30.00	28.112
3	12	5.00	20.00	18.330
4	16	3.75	15.00	13.430
5	20	3.00	12.00	10.638

Table 4: Verification Of Washing And Indexing Time

S/N	Speed (Rpm)	Washing Time (Secs)	Washing Time (Stopwatch Reading)	Indexing Time (Secs)	Indexing Time (Stopwatch Reading)
1	6	7.500	7.844	2.500	1.772
2	8	5.625	5.938	1.875	1.248
3	12	3.750	3.904	1.250	0.566
4	16	2.813	3.022	0.938	0.190
5	20	2.250	2.434	0.750	0.078

3.1.4 Results of Experimentation with Test Rig

The test rig was run five times for each selected speed and the cycle time, washing and indexing time were recorded from a handheld digital stopwatch. The results were tabulated and shown in table 5.

Table 5: Cycle Time, Washing Time, Indexing Time at Different Speeds

Speed (Rpm)	**Time (Seconds)**	**First Test Run**	**Second Test Run**	**Third Test Run**	**Forth Test Run**	**Fifth Test Run**
5	**Cycle time**	38.13	38.03	38.05	37.95	38.14
	Washing time	7.89	7.96	7.64	7.84	7.89
	Indexing time	1.76	1.46	2.12	1.69	1.81
7	**Cycle time**	28.06	28.13	28.03	28.18	28.16
	Washing time	5.91	5.97	5.92	5.99	5.90
	Indexing time	1.26	1.24	1.27	1.22	1.25
12	**Cycle time**	18.34	18.39	18.25	18.33	18.34
	Washing time	3.93	3.92	3.84	3.89	3.94
	Indexing time	0.43	0.64	0.65	0.57	0.54
15	**Cycle time**	13.61	13.30	13.50	13.31	13.43
	Washing time	3.12	3.05	3.00	2.92	3.02
	Indexing time	0.08	0.12	0.31	0.25	0.19
19	**Cycle time**	10.59	10.84	10.44	10.65	10.67
	Washing time	2.39	2.62	2.29	2.41	2.46
	Indexing time	0.11	0.09	0.07	0.05	0.07

The result of the average cycle time, average washing time and average indexing time of the test rig were calculated and are shown in the table 6 below. Graphs were plotted for varying parameters using MATLAB series 9.0 software.

Table 6: Experimentation Results

S/No	Speed (Rpm)	Max.Pin-Slot Contact Force (N)	Cycle Time (Secs)	Washing Time (Secs)	Indexing Time (Secs)
1	5	16	38.060	7.844	1.772
2	7	17	28.112	5.938	1.248
3	12	22	18.330	3.904	0.566
4	15	25	13.430	3.022	0.190
5	19	29	10.638	2.434	0.078

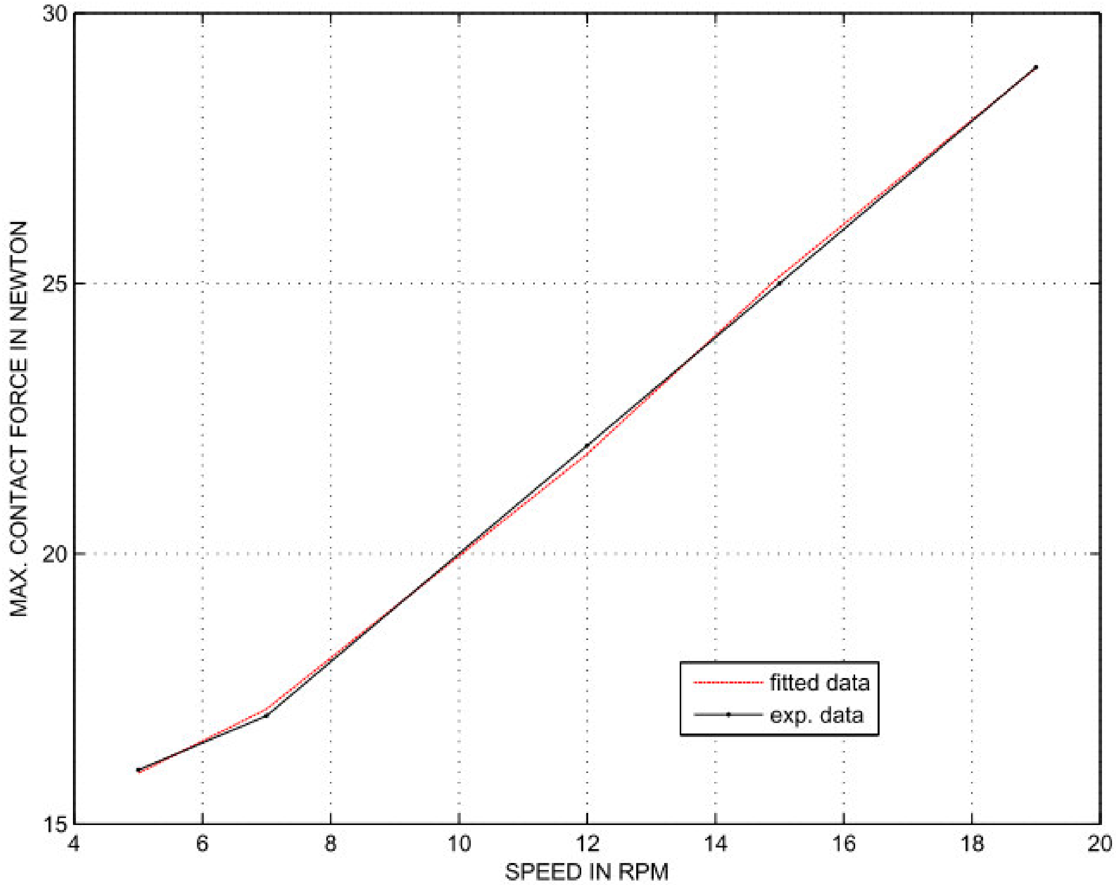

Figure 2: Plot of Maximum pin-slot contact force against Speed

$$Y = 16.06 - 0.003138X^3 + 0.1256X^2 - 0.5734X \qquad (R^2 = 0.9995)$$

The relationship between maximum pin-slot contact force of the Geneva mechanism and speed of the driver is a third order polynomial with R square (R^2) value of 0.9995. The line of best fit shown in red line is very close to the experimental curve. As the maximum pin-slot contact force increases from 16N to 29N, the speed of the driver increases from 5rpm to 19rpm.

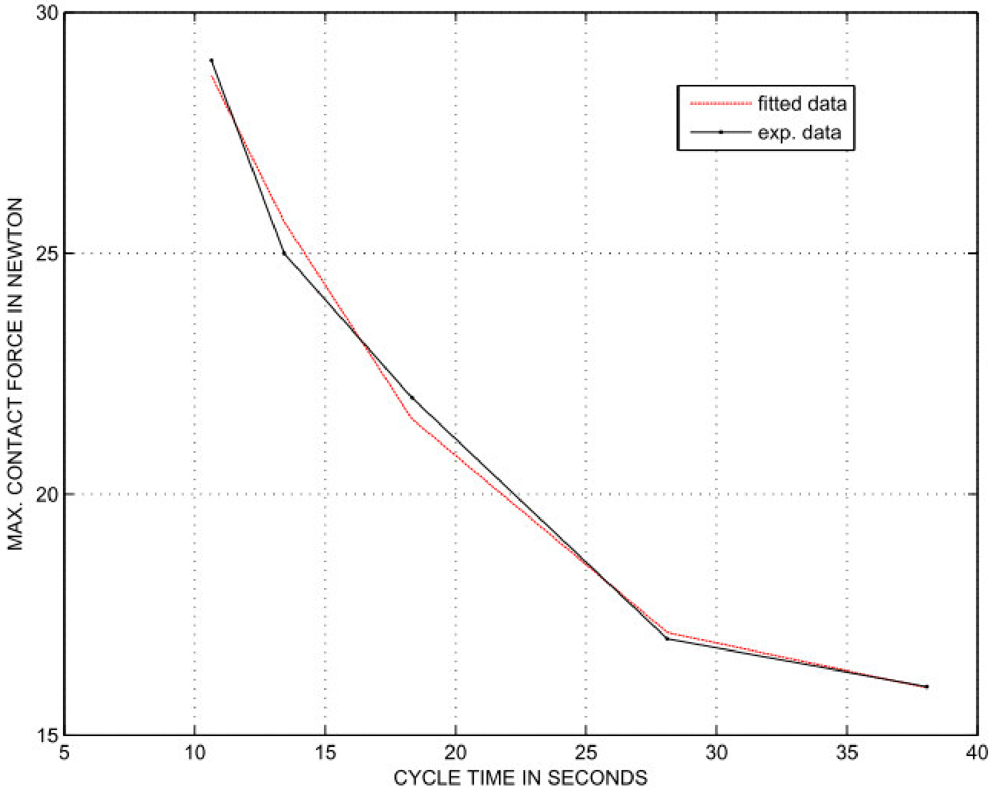

Figure 3: Plot of Maximum pin-slot contact force against Cycle time

$$Y = 45.87 - 0.0003685X^3 + 0.0482X^2 - 2.086X \qquad (R^2 = 0.9938)$$

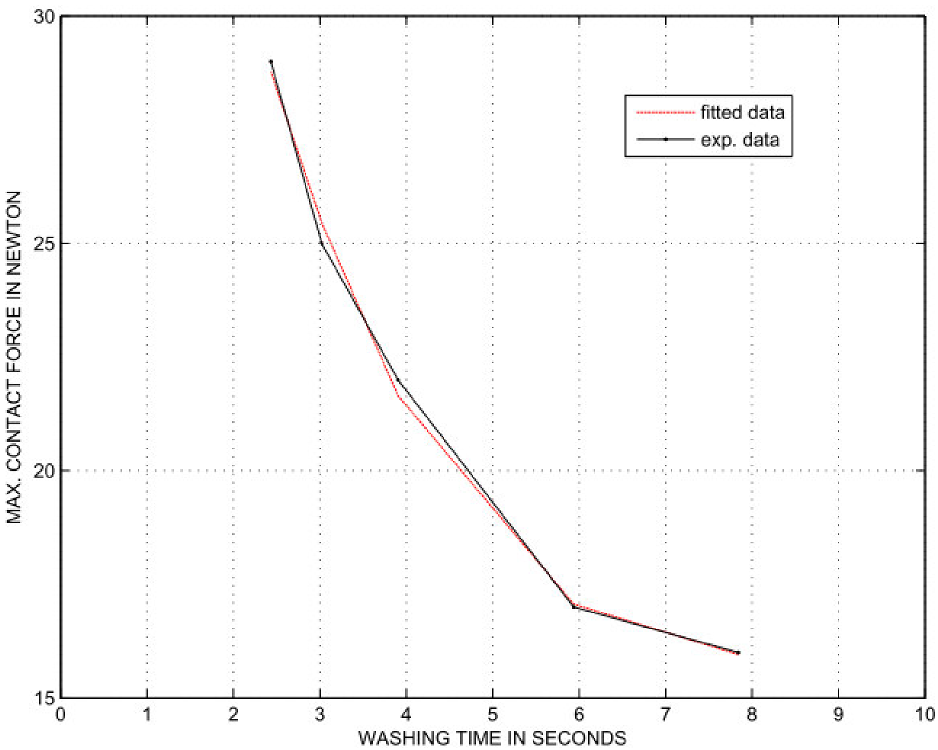

Figure 4: Plot of Maximum pin-slot contact force against washing time

$$Y = 50.88 - 0.05805X^3 + 1.452X^2 - 12.27X \qquad (R^2 = 0.9968)$$

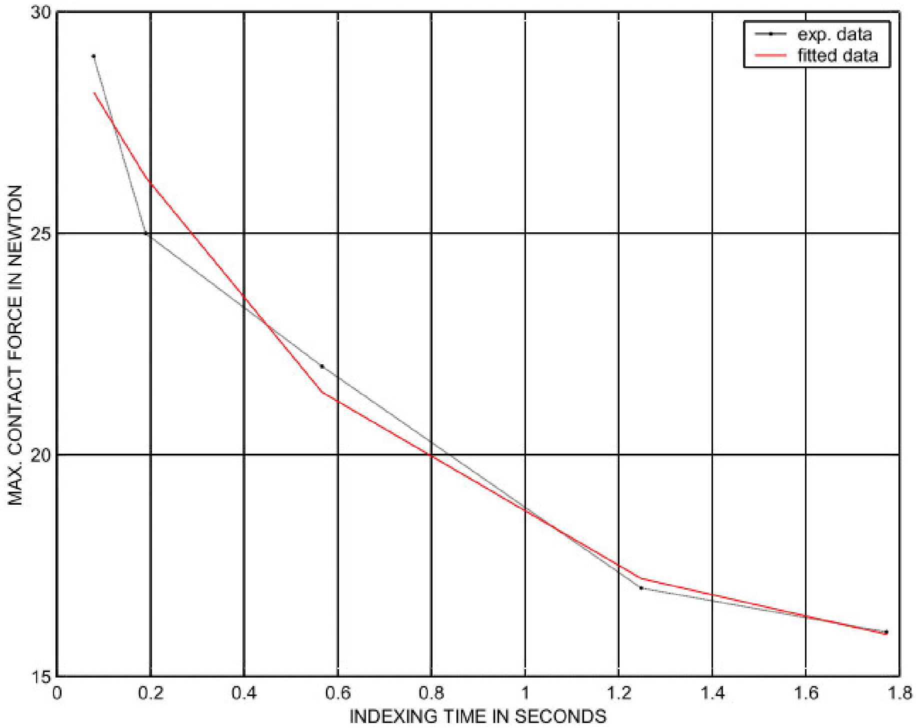

Figure 5: Plot of Maximum Pin-Slot Contact Force against Indexing Time

$$Y = 29.67 - 2.041X^3 + 10.45X^2 - 19.85X \qquad (R^2 = 0.9776)$$

From figure. 2 to fig. 5 above, the relationships between maximum pin-slot contact force of the Geneva mechanism and Cycle time, washing time and indexing time are third order polynomials. As the maximum pin-slot contact force increases from 16N to 29N, the cycle time, washing time and indexing time decreases from 38.060 seconds to 10.638 seconds, 7.844 seconds to 2.434 seconds and 1.772 seconds to 0.078 seconds respectively. The lines of best fit shown by a red line in figs. 2 to 4 are very close to the experimental curves.

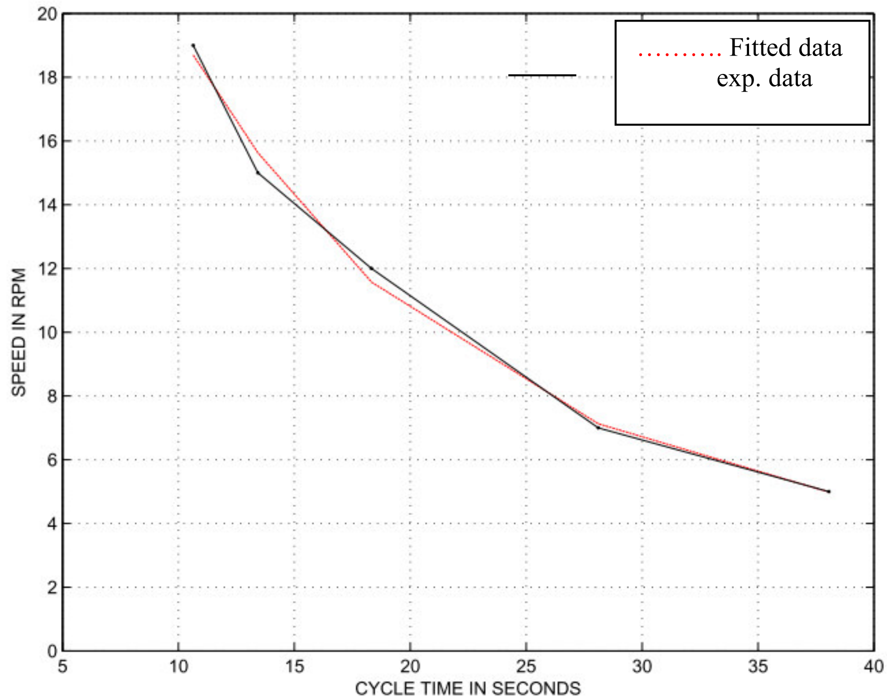

Figure 6: Plot of Driver speed against Cycle time

$$Y = 36.81 - 0.0005446X^3 + 0.05811X^2 - 2.259X \qquad (R^2 = 0.9947)$$

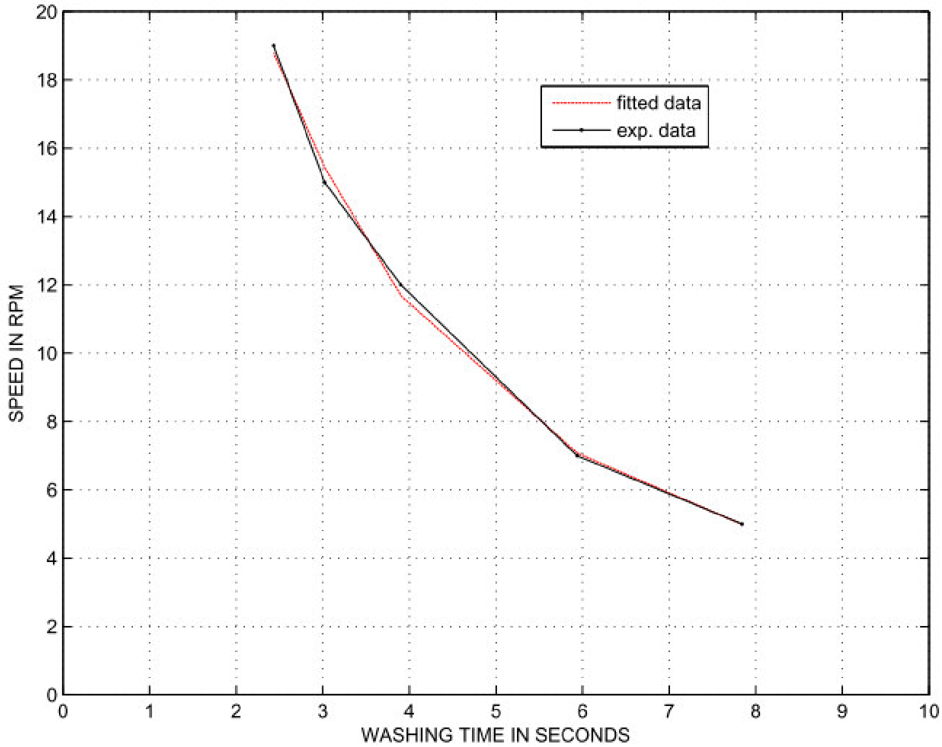

Fig 7: Plot of Driver speed against washing time

$$Y = 42.16 - 0.0814X^3 + 1.735X^2 - 13.34X \qquad (R^2 = 0.9974)$$

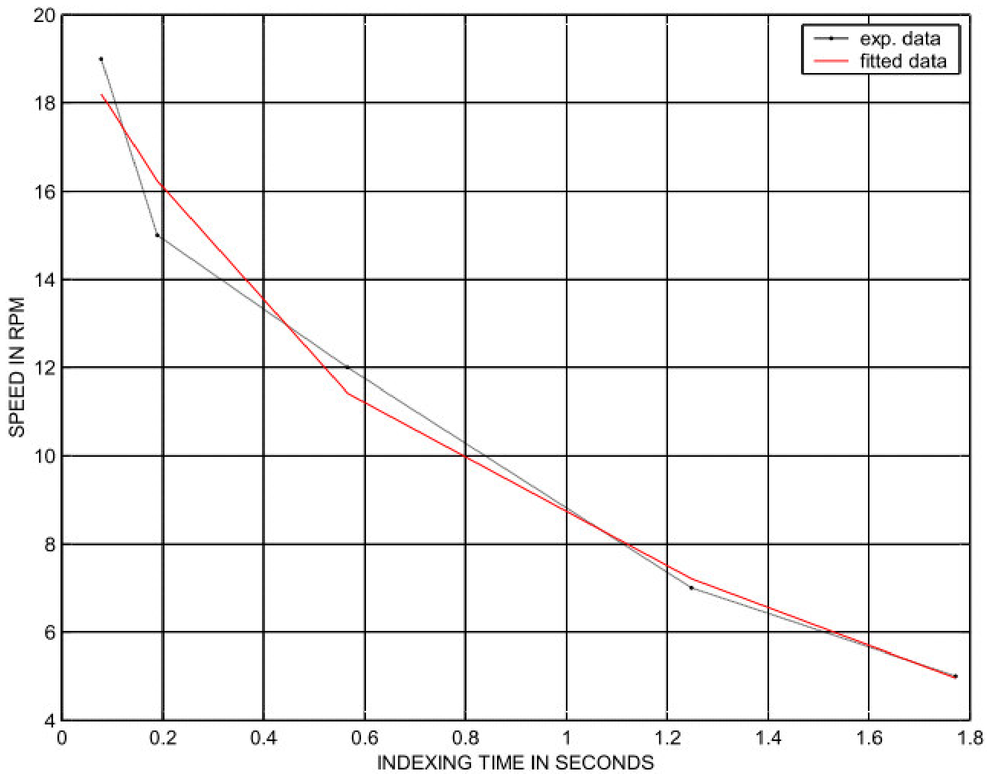

Fig 8: Plot of Driver speed against indexing time

$$Y = 19{,}74 - 2.954X^3 + 12.17X^2 - 20.63X \qquad (R^2 = 0.9805)$$

From figure. 6 to figure. 8, the relationships between driver speed of the Geneva mechanism and cycle time, washing time and indexing time are third order polynomials. As the driver speed increases from 5rpm to 19rpm, cycle time, washing time and indexing time decreases from 38.060 seconds to 10.638 seconds, 7.844 seconds to 2.434 seconds and 1.772 seconds to 0.078 seconds respectively. The lines of best fit shown by a red line in fig. 6 to fig. 8 are very close to the experimental curves.

4. Conclusions

The test rig uses Geneva mechanism to index a table intermittently for bottle washing. The test rig was designed, constructed, assembled and used to run the experimental study. The test runs were performed five times for each selected speed. The cycle time obtained for selected speeds was between 10.639 seconds and 38.060 seconds, the washing time was between 2.434 seconds and 7.844 seconds and the indexing time was between 0.078 seconds and 1.772 seconds. The maximum pin-slot contact force for selected speeds was between 16N and 29N. The graphs plotted for time taken and number of bottles washed at selected speeds were all linear functions while the graphs plotted by varying other parameters such as speed, maximum pin-slot contact force, cycle time, washing time and indexing were represented by third order polynomial functions of differing coefficients and constants.

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