PERFORMANCE OPTIMIZATION of CONTINUOUSLY VARIABLE TRANSMISSION (CVT) USINGDATA ACQUISITION SYSTEMS (DAQ)

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Abstract - The CVT has components whose motion results in the change of the radius of the sheaves and thus changing the gear ratio. It is necessary to acquire the data of the changing gear ratio with respect to changing RPM of the engine. For this purpose development of a Data Acquisition System (DAQ) was necessary. This made us easier to understand the response of the CVT and the vehicle once the various components are changed which are described later. The methodology described on this paper can be used to optimize performance of any vehicle working with a CVT. A simulation program is developed to calculate theoretical timing and matched with experimental timings. This validates the methodological approach of the tuning of CVT.

Keywords - DAQ, CVT, Instantaneous responses, Corresponding movements, BAJA buggy, engagement RPM, Instantaneous gear ratio, Shift rate, Upshifts, Backshifts, Tunable Components, Roller Weights, StiffnessSprings,Cam, Torsion Spring, Belt-Tension, Optimized Performance

I. INTRODUCTION

Continuous Variable Transmission (CVT) is used in many vehicles in recent days as a component of automatic transmission. This paper deals with the methodology on how to tune the CVT as per the required performance. The experimental data is based on a 200 kg BAJA buggy participating in SAE BAJA INDIA for better acceleration and hill climb timing.

A. Abbreviations and Terminologies

1. CVT: CVT is an automatic transmission that can change seamlessly through an infinite number of effective gear ratios.

2. DAQ: Data Acquisition System

3. INT: Interrupt

4. ISR: Interrupt Service Routine

*5. I/O:*Input/Output

6. Baja SAE: Baja SAE is an intercollegiate design competition run by the Society of Automotive

Engineers (SAE), in India conducted by SAE India.

7. Hall Sensor: A Hall effect sensor is a transducer that varies its output voltage in response to a magnetic field.

8. Tuning: Customization of CVT components for vehicle’ s performance optimization.

9. Tunable Components: CVT Components which are tunable (customizable).

10. Cam: Cam is a tunable component of driven pulley, having a surface designed with curvatures to deliver the correct (tunable) side force.

11.Upshift: Forward shift in gear ratio of CVT; going from higher to lower gear ratio.

12.Backshift: Back or Reverse shift in gear ratio of CVT; going from lower to higher gear ratio

13.Flyweight: Tunable components in driving pulley of CVT having correct (tunable) weights, working on principal of centrifugal force (C.F.) given by equation “ $C.F.= m\omega^2 r$ “, where m=mass of flyweight,

ω= angular speed of driving pulley, r= distance of flyweight from rotation axis of driving pulley; accounting for engagement of belt and shifting of gear ratios.

14.EngagementRpm: Engine rpm at which the driving pulley gets engaged with the belt, thus engaging the driven pulley to impend the motion of the car.

15.Shift Rpm: Engine rpm at which the gear ratio of CVT starts shifting from a constant value. Usually, Shift Rpm is greater than Engagement Rpm.

B. Introduction

The paper describes the use of DAQ (Data Acquisition System) for gauging instantaneous responses of Comet Model 780 CVT (Continuously Variable Transmission) drive pulley, with variation in Engine RPM, and corresponding movements of driven pulley installed as a part of transmission system in a BAJA buggy. The aim is to gather information regarding static and dynamic engagement RPM, instantaneous gear ratio and the shift rate along with dynamic upshifts and the backshifts, these parameters been directly dependent upon the tunable components of Comet Model 780 CVT. These components are: the roller weights and the stiffness springs in drive pulley & the Cam and the torsion spring in the driven pulley. There is also a slight dependence upon the belt-tension of the belt driving the driven pulley.

The DAQ is used to measure the rpm of the driven and driving pulley of the CVT. The data is then used to find the gear ratio which is in turn used for CVT tuning. The rpm of the pulleys is measured with the help of a unipolar hall sensor. The hall sensor is actuated when it is subjected to North Pole magnetic field and is switched off when the magnetic field is stopped. Hence the pulleys consist of Neodymium magnet which enables the sensor when the magnetic field falls normally on the sensor surface.

The paper includes various graphs namely Gear ratio vs rpm of driving pulley and rims of Driving pulley vs driven pulley plotted using MATLAB software, which further helped tuning of the CVT as per the requirement of the terrain (For optimized performance over a straight & a gradient terrain).

The Comet Model 780 CVT comes with varieties of tunable components like the roller weights (of different weights) and the stiffness springs (of different stiffness) in drive pulley & the Cam (of different angle) and the torsion spring (of different stiffness) in the driven pulley. The change in one or more type of above tunable components, will correspondingly change the reactions of the CVT, for every given Engine RPMs. The followings (Figure 6 and 7) are the expectations.

Fig 1. Driver Pulley Internal Arrangement

Fig 2. Stiffness Spring in Driver(Purple Spring Set)

Fig 3. Roller Weight

Fig 4. Torsion Spring (Driven Pulley)

Fig 5. 41 degree cam

Fig 6. 32 degree cam

780 SERIES ENGAGEMENT CHART (RPM'S)
DRIVE TUNING PARTS
(4 CYCLE SELECTION)

	SPRING KITS				
	703548/49 GREEN	703064/65 BLUE	703066/67 YELLOW	703242/43 PURPLE	703028/29 PLAIN
ROLLER WGT. KITS	7.6 IN./#	11.3 IN/#	14.8 IN/#	20.5 IN/#	26.0 IN/#
602239 WGT: 68 GRMS. BLUE ROLLER ONLY	1650	1950	2250	2550	3500
164-0002 WGT: 71 GRMS. BLUE/CAD WASHER	1500	1700	2000	2400	3350
602235 WGT: 78 GRMS. BLUE/GOLD SIDE WASHER	1410	1680	1900	2200	3200
164-0005 WGT: 91 GRMS. BLUE/GOLD SIDE CONES	1200	1500	*MINI BAJA SPEC 1800*	2000	2400
602246 WGT: 98 GRMS. BLUE/BLUE SIDE CONES	1000	1300	1600	1850	2200
602253 WGT: 105 GRMS. BLUE/GREEN SIDE CONES	800	1100	1400	1650	2000

Fig 7. Engagement Speed Chart (Driver pulley)

CAM SELECTIONS

PART NUMBER	CAM ANGLE		AFFECT ON UPSHIFT	AFFECT ON BACK SHIFT
			REDUCES	INCREASES
703703**	32	(BAJA SPEC)	↓	↑
703274	35			
703219	41		INCREASES	REDUCES

TORSION SPRING SELECTION

PART NUMBER	COLOR CODE	NUMBER OF COILS	AFFECT ON UPSHIFT	AFFECT ON BACK SHIFT
702970	PLAIN	5	INCREASES	DECREASES
703102	BLACK	7	↑	↓
704378	BLUE	6		
704419	GREEN	6		
704483	RED	6	DECREASES	INCREASES

Fig 8. Behavior with tunable cams and torsional springs

1. *Arduino Uno Microcontroller :* The fact that Arduino Uno can be replicated on a GCB (since it has a through hole ATMega 328 chip) as a standalone Arduino Uno making it handy for rough terrain testing, reasons for incorporating it as microcontroller. The Arduino I/O Board has traditionally been based on the Atmel AVR ATmega8 and later derivatives. The I/O Board also contains a serial port, power supply circuitry, expansion connectors, and miscellaneous support components. The Arduino Uno maintains the ATmega328 with 32KB bytes of program memory, while remaining pin compatible. The nine-pin RS-232 serial connector and interface circuitry has been replaced with a virtual serial port using various USB Interface Chips.

II. EXPERIMENTAL PROCEEDINGS

A. Procedure

- Strong Neodymium magnets were attached to both the pulleys.
- The rpm of the pulleys is measured with the help of unipolar hall sensors.
- These sensors were mounted in close proximity to the pulleys so that the sensors are capable of producing output readings.
- The pulleys consisting of the magnets actuates the sensor when the magnetic field falls normally on the sensorsurface.
- The electrical module was mounted in the cockpit section and data were recorded in the module.
- The pulse produced by the sensor is read as a digital input to the Arduino which activates an external interrupt.
- The input is fed to INT0 & INT1 (external interrupt) pins of the Arduino. The interrupts are edge triggered so that multiple actuations do not take place in the same revolution.
- The time between the occurrence of two rising edges is stored and hence the frequency is determined. The Gear ratio is defined as the ratio of rpm of driving pulley to the rpm of driven pulley.
- For dynamic measurements, that is when the car is moving, the readings are stored on a SD card as a text file connected to the Arduino board. The readings can be later viewed for further analysis.
- The data were recorded for free run of the vehicle with increasing engine rpm.

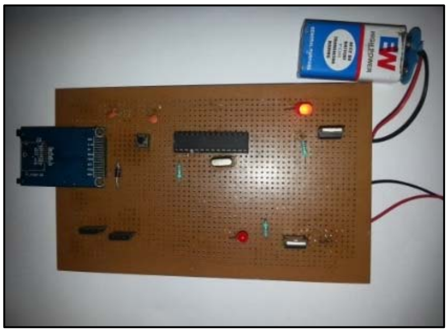

Fig 9.Arduino Board

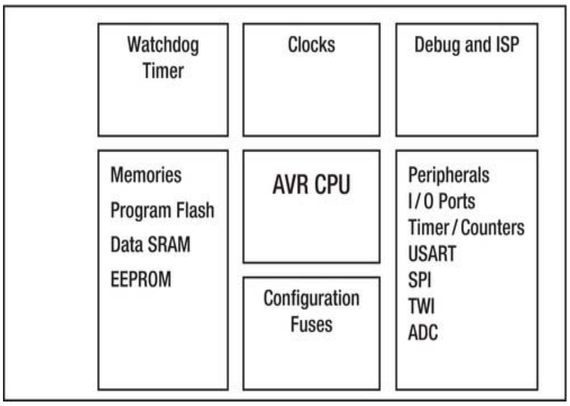

Fig 10. Simplified Block Diagram of ATMega 328

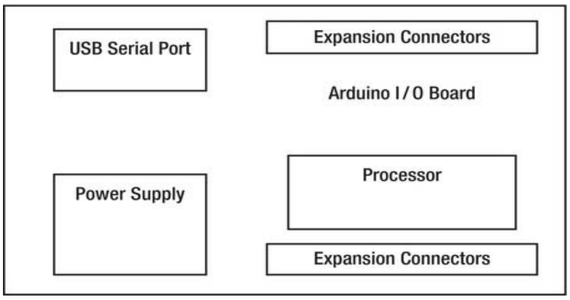

Fig 11.Arduino I/O Board Block Diagram

B. Observations

- The first set of data was recorded with primary stock set of the CVT which included 320 Cam angle, with 91gm yellow spring kit. The table in APPENDIX I represents the first data set.
- The second test was done by changing the Cam angle of the driven pulley to 410 . The data obtained is listed in table in APPENDIX II .

III. DETERMINATION OF ACCELERATION

For determining the acceleration, a SimDriveline model is constructed in MATLAB which contains simulation model of engine, gearbox and vehicle parameters. The dynamic CVT gear ratios graphs as obtained from the DAQ is used as single input for the CVT gear model in the simulation model.

A. Discussion

Car weight: 200 kg

Gear reduction: 13.25

CVT Reduction: 3.3 to 0.54

- The timer input for the first graph is:

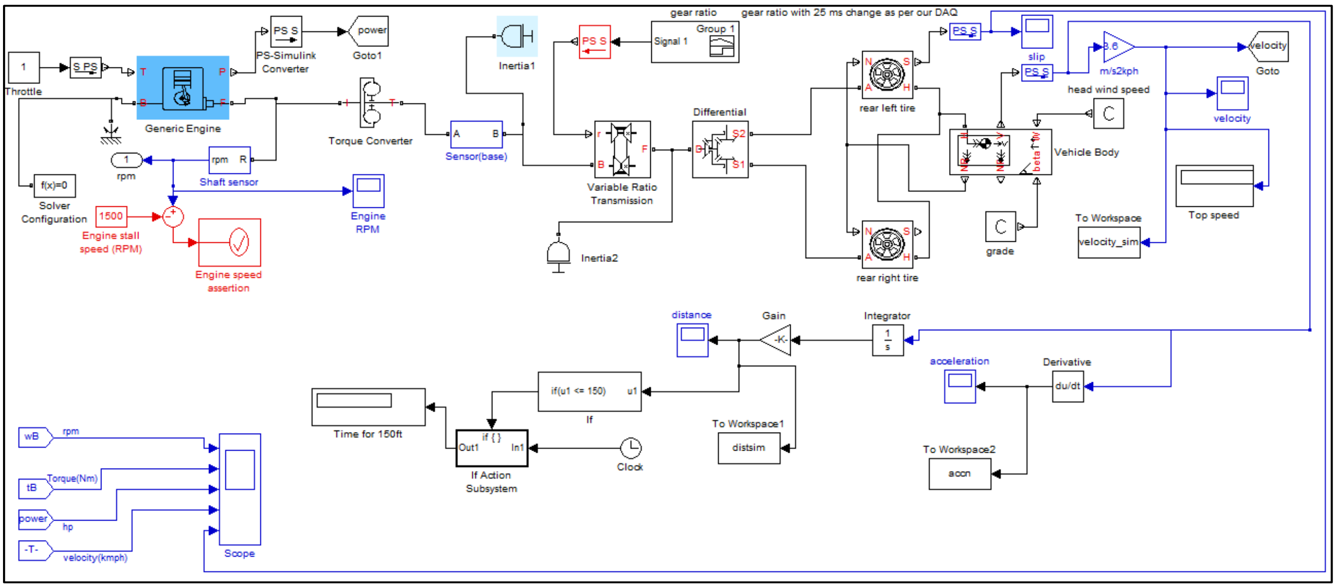

Fig 12.SimDriveline Model

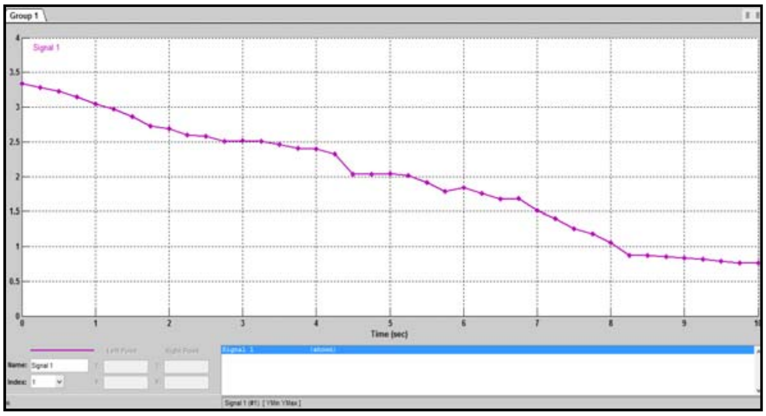

Fig. 13. Gear Ratio Vs Time Input (Sec)

- The timer input is in the form of gear ratio with respect to micro-controller reading time of 0.25 sec. The acceleration time obtained was 5.921 sec.
- Following graph was obtained on MATLab:

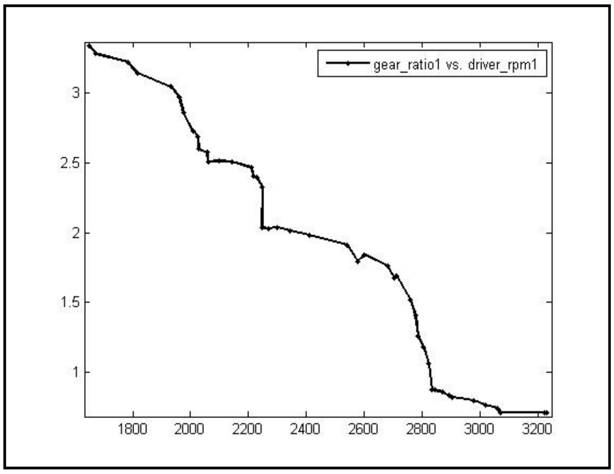

Fig. 14. Gear ratio Vs Driver Pulley RPM

- The timer input for the second graph is:

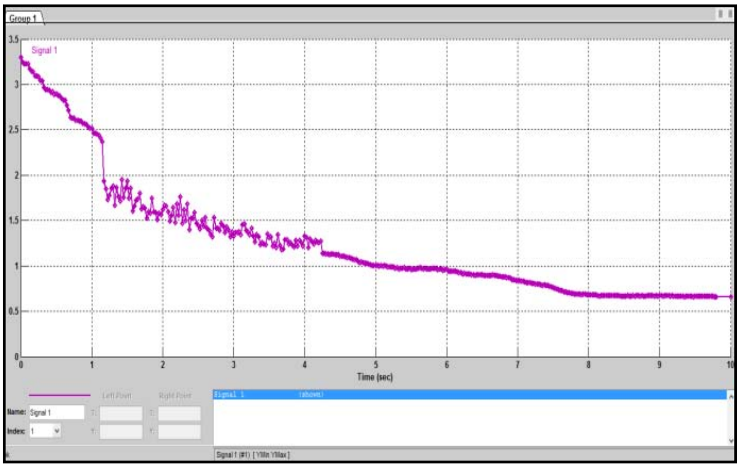

Fig 15. Gear Ratio vs Time (Sec)

- The acceleration time obtained is 5.616 sec. Thus Optimized acceleration is obtained by CVT tuning with the DAQ obtained parameters. The graph was obtained by using MATLAB.

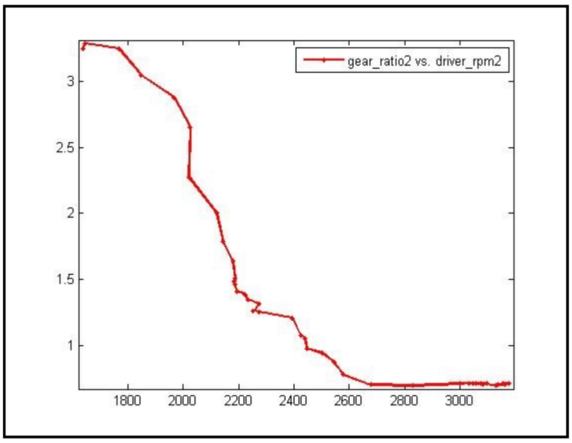

Fig. 16. Gear ratio Vs Driver Pulley RPM

B. Optimization for Hill Climb

The results were satisfactory with 41 degree Cam angle for acceleration. The 32 degree Cam angle delivered much more than the required torque to overcome the tractive effort for the acceleration of the vehicle. In the hill climb the vehicle stands at a slope of 26^0 , and it requires to accelerate on the slope. Hence there is a component of weight acting down the slope which requires additional torque to overcome it. To overcome this additional component of force the 32 degree Cam was best suitable for the event. The acceleration timing for the 35m long slope was 8.32 sec (32 degree Cam).

Cam angle 320 -8.32 sec

Cam angle 410 -8.94 sec

IV. RESULT

- Both the graphs infers that the engagement rpm is near to 1800 rpm because the value of gear ratio in both the graphs remain constant.
- The comparison of two graphs suggests that the second test results has more rapid gear change or the upshift rate is faster in the range of 2000rpm to 2800 rpm. Thus the Cam angle of 410 gives more upshift than 32^0.
- Faster upshift is required in faster acceleration as the shifting would be very fast and the engine will reach near the peak power rom much faster which is fast necessary for acceleration.

Thus we can say an increase in the Cam angle for tuning of CVT will give higher upshifts and vice versa.

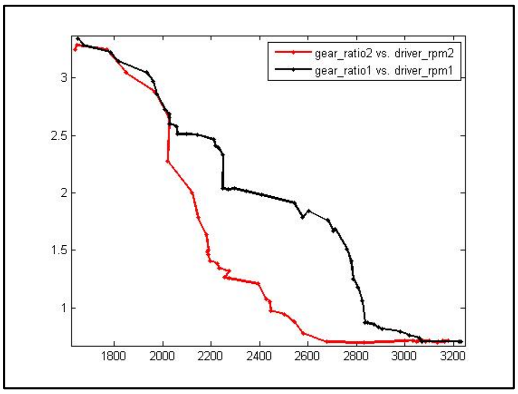

Fig. 17. Graph Comparison (Figure 14 & Figure 16)

V. CONCLUSION

We have tuned the CVT (Comet Model-780) with required parameters by tuning to get best results. The methodology will be used to get other performance parameters with other set of CVT (Gaged CVT).

VI. APPENDIX

A. Appendix 1

The following image consists of the values as acquired from the DAQ. The data is for 32^0Cam angle.

TABLE I.DAQ READINGS WITH 32 DEGREE CAM

RPM of Driving Pulley	RPM of Driven Pulley	Gear Ratio
1648.756	493.3589	3.3419
1672.813	509.3626	3.28413
1781.48	552.4312	3.2248
1815.85	577.1933	3.146
1932.24	633.833	3.0485
1960.53	659.5337	2.9726
1974.98	690.6708	2.85951
2009.38	736.2702	2.729134
2025.93	754.2602	2.685983
2027.03	779.3	2.601091
2057.05	798.51	2.576111
2059.87	820.88	2.509344
2097.9	835.24	2.511733
2142.25	854.21	2.507873
2211.41	897.13	2.464983
2216.64	920.58	2.407873
2227.83	930	2.395516
2247.53	965.13	2.328733
2246.85	1103.669	2.0358
2268.26	1116.82	2.030999
2297.641	1127.321	2.038143
2344.814	1163.284	2.015685
2408.868	1215.659	1.981533
2541.486	1329.63	1.911423
2578.21	1441.226	1.7889
2601.85	1412.268	1.84232
2681.412	1522.258	1.76147
2704.5	1617.947	1.671562
2712.48	1607.396	1.6875
2761.158	1823.991	1.5138
2777.496	1976.074	1.405563
2786.55	2221.066	1.2546
2804.681	2373.71	1.18156
2824.417	2667.234	1.058931
2835	3254.379	0.871134
2846.84	3266.223	0.8716
2871.91	3355.035	0.856
2892.4	3474.354	0.8325
2904.72	3538.027	0.821
2979.15	3749.858	0.79447
3018.11	3949.889	0.7641
3058.73	4126.727	0.7412
3062.85	4184.221	0.732
3071.88	4325.373	0.7102
3232.06	4560.226	0.70875

B. Appendix 2

The following image consists of the values as acquired from the DAQ. The data is for 41^0Cam angle.

Table II. DAQ READINGS WITH 41 DEGREE CAM

RPM of Driving Pulley	RPM of Driven Pulley	Gear Ratio
1636.48	392.74	3.246
1643.3	395.42	3.2849
1766.82	543.82	3.2489
1846.731	606.28	3.046
1966.96	542.69	2.876
2025.93	832.5	2.6548
2020.2	922.91	2.2746
2121.34	1059.17	2.002832
2145	1202.02	1.784496
2179.28	1330.26	1.638236
2187.86	1453.21	1.505536
2182.77	1517.76	1.48762
2186	1341.92	1.4629
2194.91	1485.15	1.412
2224.53	288461.5	1.3864
2233.14	1655.08	1.349264
2273.76	1724.34	1.318626
2252.93	1783.17	1.263441
2274.11	1809.63	1.256671
2393.49	1977.33	1.210466
2425.61	2252.25	1.076972
2440.89	2418.96	1.05478
2445.79	2499.58	0.97848
2502.92	2649.71	0.944601
2543.67	2902.48	0.876378
2578.65	3301.06	0.781158
2677.62	3804.21	0.703857
2831.79	4058.44	0.697753
3000.6	4217.04	0.711542
3031.53	4226.54	0.71726
3046.92	4288.16	0.710543

3056.86	4288.16	0.712861
3075.03	4322.77	0.711356
3098.53	4326.51	0.716173
3084.52	4352.87	0.708618
3132.18	4470.94	0.700564
3156.57	4428.7	0.712753
3178.64	4452.36	0.713923
3164.56	4456.33	0.710127
3162.56	4458.98	0.709256
3137.42	4422.17	0.709475

C. Appendix 3

The Arduino code snippet is presented below as follows:

```
double rpm_1=0;
double rpm_2=0;
unsigned long timeold_1=0;
unsigned long timenew_1=0;
unsigned long starttime_1=0;
unsigned long timeold_2=0;
unsigned long timenew_2=0;
double diff_1=0;
double diff_2=0;
#include<SD.h>
File dataFile;
constintchipSelect = 4;
void setup()
{
attachInterrupt(0, rpm_fun_1,FALLING);
attachInterrupt(1, rpm_fun_2,FALLING);
rpm_1 = 0;//Driving Pulley
timeold_1 = 0;
timenew_1=0;
rpm_2 = 0;//Driven Pulley
timeold_2 = 0;
timenew_2=0;
Serial.begin(9600);
pinMode(10, OUTPUT);
if (!SD.begin(chipSelect))
{
Serial.println("Card failed, or not present”);
return;
}
}
void loop()
rpm_1=0;
else
{
diff_1= timenew_1-timeold_1;
rpm_1= (60000000.0/diff_1);
}
 timeold_1=timenew_1;
}
 void rpm_fun_2()// Driven Pulley
{
 timenew_2=micros();
 if(timenew_2==timeold_2)
 rpm_2=0;
else
{
 diff_2= timenew_2-timeold_2;
 rpm_2= (60000000.0/diff_2);
 }
 timeold_2=timenew_2;
}
```

```
{
if((millis()-starttime_1)==250)
{
File dataFile = SD.open("datalog.txt",FILE_WRITE);
dataFile.println("\n");
dataFile.print(rpm_1);
rpm_1=0;
dataFile.print("\t\t\t");
dataFile.print(rpm_2);
rpm_2=0;
dataFile.print("\t\t\t");
dataFile.close();
diff_1=0;
starttime_1=millis();
diff_2=0;
}
}
void rpm_fun_1()//Driving Pulley
{
timenew_1=micros();
if(timenew_1==timeold_1)
```

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Nitesh Lohia is doing his B.Tech in Mechanical Engineering from VIT University Vellore India. He is currently in the final year of his engineering course. He is the senior member of the transmission department of the BAJA SAE Team Kshatriya. He is also the recipient Special Achievers Chancellor’s Award for his contribution in the team. His Field of interests includes Automotive Engineering and Aerospace Engineering.