Vol. XV & Issue No. 06 June - 2022
INDUSTRIAL ENGINEERING JOURNAL

MANUFACTURING AND TESTING OF AN INFINITELY VARIABLE TRANSMISSION (IVT) TEST RIG

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Abstract

The manual gearbox in the vehicles can be very tough for the driver as the driving requires frequent shifting of gears for achieving optimal transmission ratio. In the Infinitely variable transmission (IVT) system, it eliminates the shifting of gear change operations for driver and ensures the optimal transmission ratio. This paper objective is to design a compact and simple to operate infinitely variable transmission (IVT) test rig by benchmarking the William Terry Lester IVT system and selecting the right material from PSG design data book and to compare the actual torque with theoretical torque across speed, the input torque with the output torque on the manufactured IVT test rig.

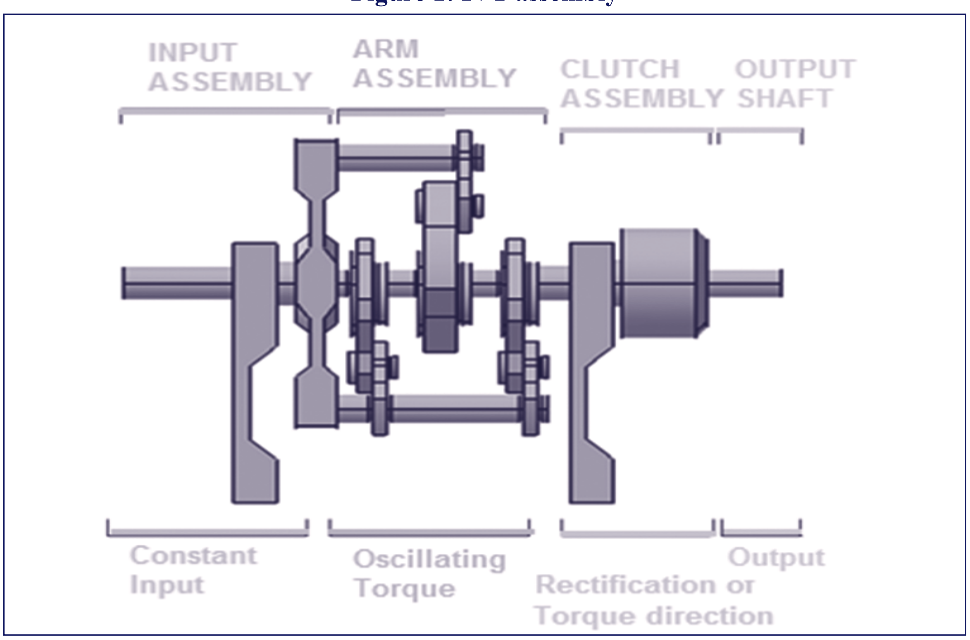
Keywords: IVT, Infinitely, variable, transmission, gearbox, testing, CVT

1. INTRODUCTION

Growing demand from customers and government legislation for more fuel efficient and less polluted vehicles has increased the making of an electric vehicle and thereby also the alternative of manual transmission system for example the Continuously Variable Transmission (CVT) system. The burden of the government legislation can be clearly observed in the "FAME India Scheme" publicized on the 09-July-2019 under Ministry of Heavy Industries & Public Enterprises. It strongly encourages roadmap for the faster adoption of electric vehicles and their manufacturing in the country. Based on the experience gained during Phase 1 of FAME Scheme and suggestions of various stakeholders including industry associations, the Department of Heavy Industry notified Phase-II of the Scheme, vide S.O. 1300 dated 8th March 2019, with the approval of Cabinet with an outlay of Rs. 10,000 Crore for a period of 3 years commencing from 1st April 2019 is allotted.

Using a manual gearbox in an electric vehicle doesn't provide the right combination or the desirable results. Currently, the electric vehicle is equipped with the Continuously Variable Transmission (CVT) e.g. MG ZS EV Sport utility vehicle uses CVT 1-speed automatic gearbox. However, CVT requires a torque converter which add on the cost and weight of the electric vehicle. One of the alternatives to avoid the cost and weight of the CVT is by replacing it with an infinitely variable transmission (IVT) system. An IVT is principally a CVT subset only, with a zero ratio, having not much of a difference besides the IVT not really needing a torque converter since it can always be in gear as IVT uses translating gear and links to provide a high-speed ratio.

Figure 1: IVT assembly



The IVT is a new design utilizing a translating gear and links to provide a high-speed ratio in compact design, which utilizes moments produced by rotating offset masses of yoke assembly to transfer torque.

The IVT comprises input shaft, arm assembly, unidirectional clutch system and the output shaft. Each of them has a specific role and function. The input shaft takes the input from the Engine and delivers it to the arm assembly for creating oscillating torque. The unidirectional clutch assembly resolves that oscillating torque to a single direction, and the output shaft conveys the output to the differential transmission.

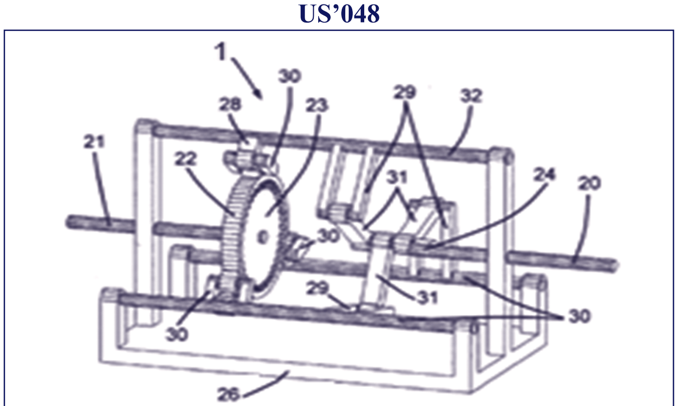
Now the purpose of this report study is to design a consistent and efficient IVT test rig, all components from the existing IVT will be analysis in detail and has been modified accordingly. The IVT test rig is designed to study the various characteristics that is to compare the actual torque with theoretical torque across speed, the input torque with the output torque on the manufactured IVT test rig.

2. LITERATURE REVIEW OF IVT SYSTEM BASIC

At first sight prior arts related to IVT system realistic for a vehicle transmission is searched for, interestingly we found Mr. William Terry Lester has patented two patents publicized in 2012, Pat no. US8663048 (US'048) and 2015, Pat no. US8967007 (US'007) relevant to the IVT system. We also found a study report published in SAE 2005 World Congress & Exhibition, Author(s): William Terry Lester and Affiliated: Lestran Engineering.

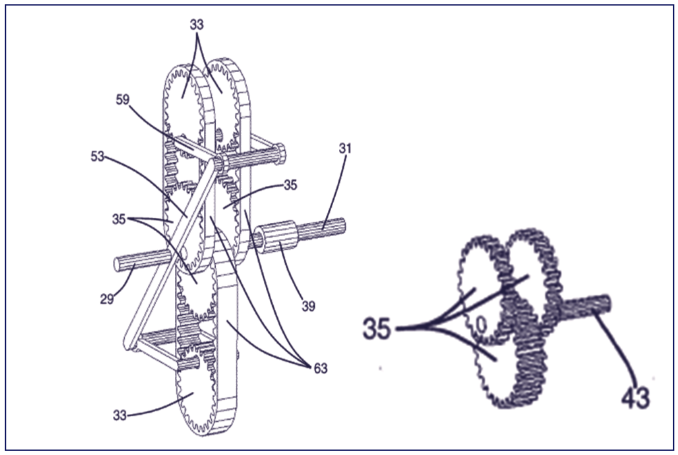
The US'048 patent discloses a gear set, comprising: an input 21 and an output 20, with a speed ratio between the input and the output, a first gear 22 that rotates, the first gear provides a circular path for a second gear 23 that is engaged with the first gear 22 , the first gear 22 connected to one of the input or the output, the second gear 23 engaged with the first gear 22 and translating in the path relative to the first gear 22 connected to the other of the input or the output, a frame 26 that is fixed relative to the first gear 22, the frame 26 being coupled to the second gear 23 by three or more linkages (30, 31) and a crankshaft 24 where the linkages are configured to (1) constrain rotation of the second gear 23 , (2) translate the second gear 23 about rotational path, and (3) transmit torque and power between the second gear 23 and the crankshaft 24.

Figure 2: William Terry Lester IVT System as explained in US'048



The US'048 patent discloses a transmission 15, comprising: rotatable input member 29, which is rotated by a rotational, power source, one or more rotatable masses 33, where the rotatable masses 33 are sprockets 45, a shaft member 43 with an eccentrically offset sprocket for each the rotatable mass.

Figure 3: William Terry Lester IVT System as explained in US'007



Where the shaft member rotatably coupled to a casing, where the rotatable masses are rotatably coupled to the eccentrically offset sprockets 35 by timing belts or timing chains 63 where the centrifugal load of the rotatable masses are held by the timing belts or timing chains, the rotatable input member 29 coupled to the rotatable masses 33 by one or more linkages so that rotation of the input member causes the rotatable masses 33 to rotate about the eccentric offset sprockets 35 and the timing belts or the timing chains transfers the centrifugal loads of the rotatable masses 33 to the eccentrically offset sprockets 35 which generates an oscillating torque to the shaft member, first and second one-way clutches 39 to convert the oscillating torque to unidirectional torque are coupled between the casing, the shaft member 43 and an output member, the first one-way clutch and the shaft member drive the output member in the output direction when the shaft member is rotating in the output direction, the second one-way clutch and the casing prevents the shaft member from rotating in the other direction.

We also found Giacomo Mantriota research paper disclosing a work on experimental results obtained for a parallel-IVT prototype. The main goal of this work is to appraise the IVT performances in terms of torque, power flows and efficiency.

Philip Duncan Winter and Christopher Greenwood patent GB2519908 aim of this invention is to provide a transmission system that provides drive characteristics that provide a low-speed, high torque drive in forward and reverse directions without the power losses associated with existing drives that incorporate a torque converter.

The objective of the proposed study was to develop an IVT test rig to realize the construction and operation of IVT. We have designed an IVT test rig which will be useful to test and study the various characteristics that is like to compare the actual torque with theoretical torque across speed, the input torque with the output torque on the manufactured IVT test rig.

3. MATERIAL SELECTION OF VARIOUS COMPONENTS OF THE IVT TEST RIG

The IVT test rig manufacturing involves data collection phase where the collection of reference material for IVT design were done. The awareness and information about the IVT are taken from Lester, W Infinitely Variable Transmission Utilizing Oscillating Torque, SAE Technical Paper 2005-01-1468 2005. The standard components are, referred and selected as desired from the PSG design data handbook. Raw material sizes for components are also determined. The following point are giving light on the same:

3.1 Material of Input Shaft

From PSG design data book [9]. – Page no. – 1.10, 1.12 & 1.17

Table no. 1 – Selection of material for input shaft

Material	Ultimate Tensile Strength (N/mm2)	Yield Strength (N/mm2)
EN24	720	600

EN24 is found to be suitable material for the input shaft as Allowable shear stress is found to be at least 130 N/mm2 and considering the same with the help of the tension load formula diameter of input shaft is calculated as 4 mm (round figure of 3.96 mm).

3.2 Material of Output Shaft

From PSG design data book [16]. – Page no. -1.17, 1.20.

Table no. 2 – Selection of material for output shaft

Material	Tensile Strength (N/mm2)	Yield Strength (N/mm2)
EN19	720	600

EN19 is found to be suitable material for the input shaft as Allowable shear stress is found to be at least 130 N/mm2 and considering the same with the help of the tension load formula diameter of input is calculated as 4 mm (round figure of 3.96 mm).

3.3 Material of Output Yoke

From PSG design data book [9]. – Page no. – 1.12, 1.17 & 1.10.

Table no. 3– Selection of material for output yoke

Material	Tensile Strength N/mm2	Yield Strength N/mm2
C40	600	380

C40 is found to be suitable material for the input shaft as Allowable shear stress is found to be at least 150 N/mm2 and considering the same with the help of the tension load formula diameter of input is calculated as 6.65 mm.

3.4 Material of Connecting Link

From PSG Design Data book [9]. – Page no. 1.10, 1.12 & 1.17.

Table no. 4 – Selection of material for connecting link

Material Designation	Tensile Strength N/mm2	Yield Strength N/mm2
EN9	600	380

Connecting link under direct tensile load is check as found to be safe as, $F_{t\,act} < F_{t\,all}$.

3.5 Material of Mass-1

From PSG Design Data book [9]. – Page no. – 1.10, 1.12 & 1.17.

Table no. 5 –Selection of material for Mass -1

Material Designation	Tensile Strength N/mm2	Yield Strength N/mm2
EN9	600	380

Under direct tensile load at the eye end of mass 1 (where the lever pin fits), EN9 is found to be safe as, $F_{t\,act} < F_{t\,all}$.

3.6 Material of Mass-2

From PSG Design Data book [9]. – Page no. – 1.10, 1.12 & 1.17.

Table no. 6– Selection of material for Mass -2

Material Designation	Tensile Strength N/mm2	Yield Strength N/mm2
EN9	600	380

Under direct tensile load at the eye end of mass 1 (where the lever pin fits), EN9 is found to be safe as, $F_{t\,act} < F_{t\,all}$.

3.7 Selection of One-Way Clutch CSK 20

Table no. 7 – Selection of one-way clutch CSK 20

IsI No.	Bearing of basic design No. (SKF)	D	D1	D	D2	B
CSK20	6204	20	26	47	41	14

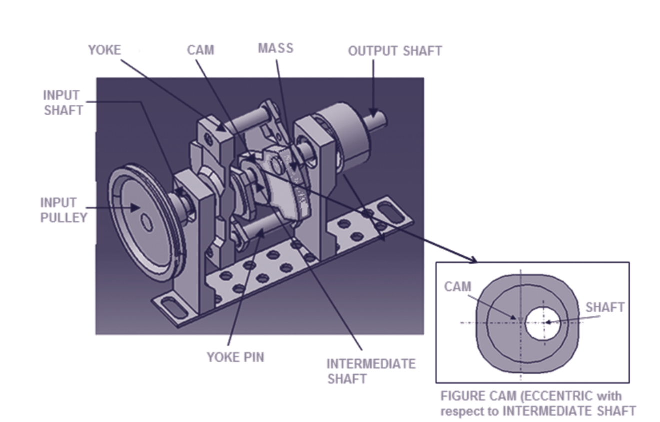
Basic Capacity of CS K20 is of the range between 6500 to 10000.

The CSK20 material is selected as the required dynamic capacity of bearing is less than the rated dynamic capacity of bearing.

4. DEVELOPMENT OF IVT TEST RIG

Benchmarking the Lestran IVT system as explained in the chapter 2, a dynamometer based IVT test is designed specifically sized to match the requirements for dynamometer testing and to study the specific characteristics like torque, power and efficiency across the speed. Figure 4 shown as Isometric view of the Input and Arm Assemblies of the Infinite variable transmission system (IVT) system.

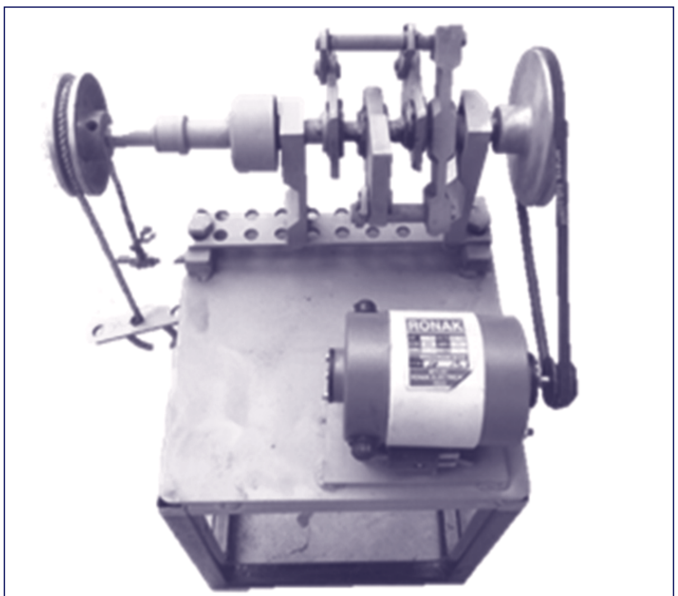
Figure 4 Isometric view of the Input and Arm Assemblies of the Infinite variable transmission system (IVT)



In the developed IVT test rig, a V-belt drive is connected in between the motor (acting as engine source) output shaft and the input shaft of the IVT, the IVT will acquire input from the motor/engine as shown in figure 5. Figure 5 depicts the IVT test rig manufactured by the assembly explain in chapter 1 & 2 and by selecting the material(s) of the key components of the IVT test rig as explain in chapter 3.

Working principle of the IVT test rig as shown in figure 5 is explained hereafter, the input shaft will convey the torque to a yoke assembly. The yoke comprises two pins projecting from it as illustrated in figure 4. The yoke is a links structure connected via pins to the input shaft at one end and to the output shaft at another end. The links via pins are connected to three masses in between the input and output shaft for generating the oscillating torque. These masses are connected to the arm assembly. The central nervous system of the IVT is the method in which the masses work with the arm assembly with each other. The arm assembly with the rotation of masses allows generating oscillating torque. This generated oscillating torque conveyed to the output shaft of differential gearbox.

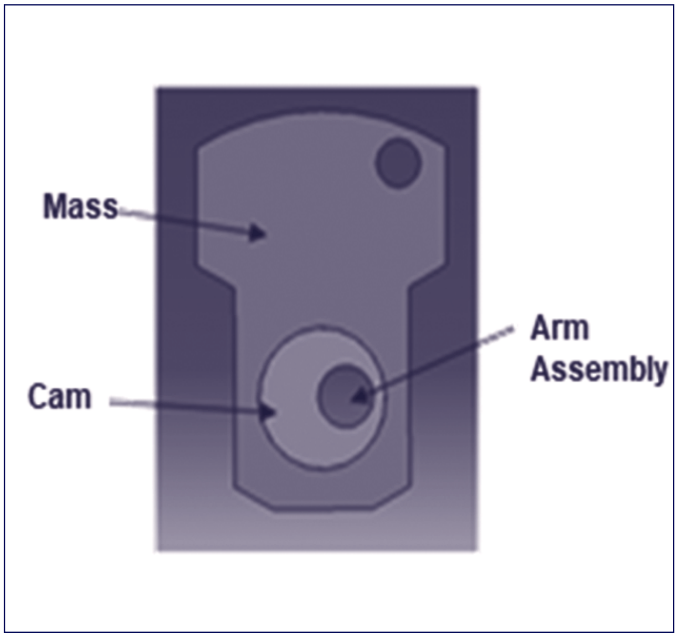
Figure. 5 IVT Test Rig



The intermediate shaft of the arm assembly has three cams mounted on it as shown in figure 4. The center cam is lengthier than the other two cams to have the balancing of the transmission. The length of cam decided according to the dimensions of masses. The weight of central mass is equal to the weight of addition of other two masses.

These cams are made as a hollow circular fragment of metal in the present IVT test rig it is steel, having an offset bore as shown in figure 4 or 6. As the center of the cam is offset from the center of the shaft, the forces acting radically on the cam is translated into a moment arm on the shaft and it ensures the balancing of the shaft. The centrifugal forces generate create a moment about the arm assembly shaft as the masses rotates around the cams.

Figure 6 – Cam arranged within the Mass at an offset



The following steps explains the oscillatory nature of the torque produced by the IVT.

In step one the rotating masses produce the centrifugal forces thus; it does no moment is generating. Then in the step two, the centrifugal forces generate a clockwise torque, as the masses have continued to rotate. Then further in step three the masses continuing to rotate to the point where their centrifugal forces once again pass through the point of rotation, thus it will cause no moment. Lastly, in the step four the masses have rotated so that their forces will produce a counter-clockwise torque. For this the maximum torque is calculated by the formula: T = m.ω2.RCG.DCam Offset

The centrifugal force is proportional to the square of rotational speed. When the rotational speed of the masses increases, the resistances on the assembly shaft will be overcome by the moment developed and the assembly shaft will initiate to rotate. Thus, arm assembly rotating to achieve one of the above-explained steps. The rotation of the masses about the cam will be declining as the rotation of the arm assembly raises. With time the torque oscillations will approach infinity thus IVT will work in direct connection between input and output. To convert the oscillating torque into unidirectional motion (as torque pulses), in IVT uses pair of one-way clutches. The first set of clutches is located in between the arm assembly and a protection case of the arm assembly. The second clutch system is located in between the output shaft and the arm assembly.

5. IVT TEST RESULTS AND DISCUSSION

In order to conduct experimental test, a weight pan is fastened on the output shaft of the IVT test rig as shown in figure 5. Specification of the AC motor is: 230 volt, 0.5 amp, 50 watt, 50 Hz, 200 to 9000 rpm. The motor is start by turning electronic speed variation knob. Letting it to run & stabilize at around 1200 rpm. Then placing 150 gm and then adding 100 gm weight into the pan on dyno-brake pulley. Further, by using a tachometer, the output speed is measured and note down to compare the actual torque with theoretical torque across speed, the input torque with the output torque on the manufactured IVT test rig.

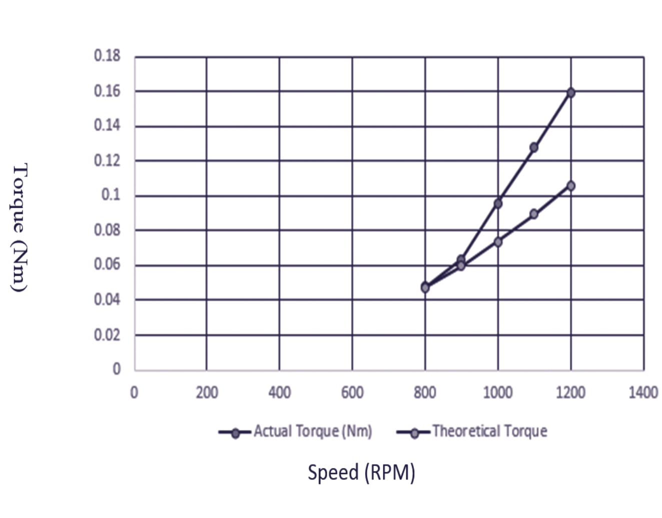
Dynamometer testing IVT test were recorded as shown in tables below. For the simplicity of calculation, the input torque is kept as 0.2002 N-m for all the load and speed variation.

5.1 Comparison of Actual Torque and Theoretical Torque across Speed

Table no. 8 – Validation of the results

Load (Kg)	Speed (RPM)	Actual Torque (Nm)	Theoretical Torque (Nm)
0.15	800	0.047824	0.047214
0.2	900	0.063765	0.059755
0.3	1000	0.095648	0.073772
0.4	1100	0.12753	0.089264
0.5	1200	0.159413	0.106231

Figure 7: Comparison of Actual and Theoretical torque across speed



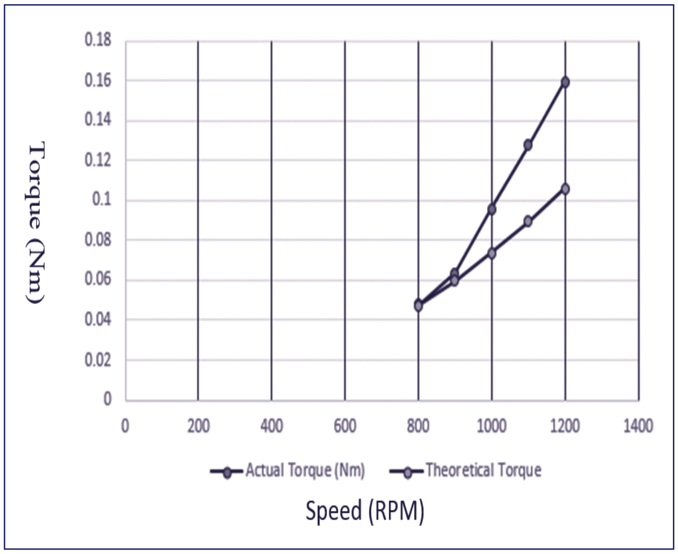
The IVT test rig as shown in figure 5 were tested to compare the actual torque with respect to the theoretical torque. The test is carried out by varying the load and speed. The actual torque and the theoretical torque are found to be approximately same for the speed in between 800 to 900 rpm whereas the actual torque is better for the speed above 950 rpm compare to the theoretical torque.

5.2 Comparison of Input Torque and Output Torque.

Table no. 9 - Comparisons of Input Torque and Output Torque

Load (Kg)	Speed (RPM)	Input Torque (Nm)	Output Torque (Nm)
0.15	800	0.06373	0.047824
0.2	900	0.08492	0.063765
0.3	1000	0.12746	0.095648
0.4	1100	0.17	0.12753
0.5	1200	0.2125	0.159413

Figure 8: Comparison of Input and output torque across speed



The IVT test rig as shown in figure 5 were tested to compare the input torque with respect to the output torque. The test is carried out by varying the load and speed. The input torque and the output torque are found to be approximately same for the speed 800 rpm whereas on further with increase in speed the difference between the output torque and input torque gradually increases.

6. CONCLUSION

The designed IVT test rig is a combination of right material selected from the PSG design data book and a simple version of the Lester IVT system with the factors for example weight and cost considered and discussed in this report. Implementing these design considerations, results the IVT became simpler, stronger and more compact. Further, the test and trials has been taken on the IVT test rig. The actual torque and the theoretical torque are found to be approximately same for the speed in between 800 to 900 rpm whereas the actual is better for the speed above 950 rpm compare to the theoretical torque. The input torque and the output torque are found to be approximately same for the speed 800 rpm whereas on further with increase in speed the difference between the output torque and input torque gradually increases. The Infinitely Variable Transmission system run exceptionally smooth while the testing. This modeling of the IVT for an automotive application specifically for the electric vehicle is demonstrating its high-performance characteristics.

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