Conversion Of Pneumatic To Electrically Actuated Waste Gated Turbo Charger

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Abstract--- This paper presents the conversion of pneumatic actuated waste gated turbo charger to electrically actuated waste gated turbo charger using a DC brushed motor. In recent years, the turbo charger is one of the basic accessories in a heavy vehicle. Its function is to enable more amount of fresh charge and enhance the development of power. The need of compactness and higher efficiency for a turbocharger in automotive application allows reduction in power consumption. To address the above criteria, study has been carried out to develop a compact waste gate turbocharger which is electrically actuated. Electric actuator consists of a electric motor with speed reducing gear and a output linear actuator to operate the waste gate valve. The advantage over the conversion of pneumatic to electric are better response increase turbine efficiency The angle of valve opening can be manipulated as required ,enabling the turbocharger to run at its maximum efficiency speed for most time.

Keywords: pneumatic actuator, force, pressure, stroke length

I. Introduction

The power generated by an internal combustion engine depends on the air mass and the quantity of fuel which can be fed to the internal combustion engine. If it is desired to increase the power of the internal combustion engine, it is necessary to feed in more combustion air and fuel. This increase in power is brought about in an induction engine by increasing the cubic capacity or by raising the rotational speed. A technical solution which is often adopted in order to increase the power of an internal combustion engine is supercharging.

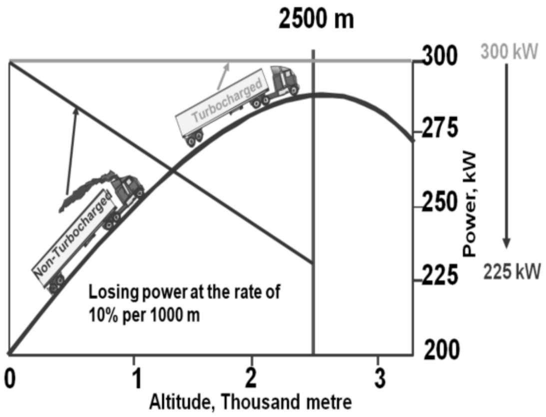

Fig. 1: Turbo charger

An exhaust gas turbocharger is essentially composed of a compressor and a turbine, which are connected to a common shaft and rotate at the same rotational speed. The compressor sucks in fresh air and feeds the pre-compressed air to the individual cylinders of the engine. An increased quantity of fuel can be fed to the relatively large quantity of air in the cylinders, as a result of which the internal combustion engine outputs more power. The combustion process is additionally favourably influenced, with the effect that the internal combustion engine has a higher overall efficiency level.

II. Waste Gated Turbo Charger

In internal combustion engines with a large operating rotational speed range, for example in internal combustion engines for passenger cars, a high charging pressure is already required at low rotational speeds of the engine. For this purpose, a charging pressure control valve, referred to as a Waste gate valve, is introduced into these turbochargers. By selecting a corresponding turbine casing, a high charging pressure is built up even at low rotational speeds of the engine. The Waste gate valve then limits the charging pressure to a constant value as the rotational speed of the engine increases.

If the rotational speed of the rotating parts were to be unacceptably exceeded, the rotating parts would be destroyed, which would amount to the turbocharger being totally written off. Depending on the configuration of the turbocharger, complete destruction of the turbocharger occurs even if the rotational speed limit is exceeded by only approximately 5%.

Fig. 2: Waste gated Turbo charger

Waste gate valves which, according to the prior art are controlled by a signal resulting from the generated charging pressure, have proven useful for limiting the rotational speed.

If the charging pressure exceeds a predefined threshold value, the Waste gate valve opens. The charging pressure and the rotational speed of the turbine wheel and of the compressor wheel are reduced. However, this control is relatively slow acting since the build-up in pressure, when the rotational speed of the rotating parts is exceeded, occurs with a time delay. For this reason, the control of the rotational speed of the turbocharger with monitoring of the charging pressure must occur in the highly dynamic range (load change) by correspondingly reducing the charging pressure at an early point, which leads to a loss of efficiency.

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K16 Turbo charger is internal waste gated turbo charger used in TATA 497 SPTC 43.The engine specification is given below.

Engine Specification

ENGINE	4SPTC (BS-III)
Model	TATA 497 SPTC 43
Type	Turbo-charged, Water cooled,Direct
No. of cylinders	4-inline
Bore / Stroke	97 mm x 100 mm
Capacity	2956 cc
Max. engine output	50 - 52 kw at 3000 rpm
Max. torque	223 N-m at 1600-2200 rpm
Compression ratio	19:01
Firing order	1-3-4-2
Air filter	Dry (Paper) type
Oil filter	Spin - on type
Fuel filter	Double stage, fine filtration
Fuel injection pump	Mechanical Rotary F.I.P
Governor	Centrifugal type variable speed.
Engine oil capacity	Min. 5.5 litres
Weight of engine	315 kg (Dry)
Radiator frontal area	2260 sq. cm.
Capacity of cooling system	12 Litres

Table 1: engine specification

For the various Speed of the engine fitted with turbo charger the inlet and exhaust pressure are determined for the engine with part load condition.

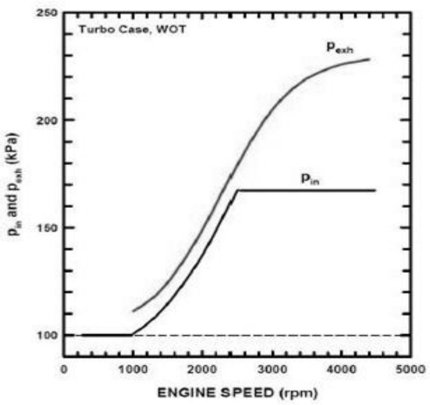

Fig. 3: engine speed vs. inlet and exhaust pressure

III. PNEUMATIC ACTUATOR

A. A. Actuator Working

As the pressure of the air being compressed by the turbocharger increases, the pressure within the sealed chamber of the actuator increases which applies a force on the spring. When the pressure is high enough to overcome the spring force, the waste gate valve begins to open, diverting exhaust gas around the turbine, allowing it to maintain its speed.

If the pressure drops, then the spring pushes the valve shut and allows the turbine to build up speed. If the pressure increases, then the valve will open further, bypassing more exhaust gas to try to maintain the desired pressure.

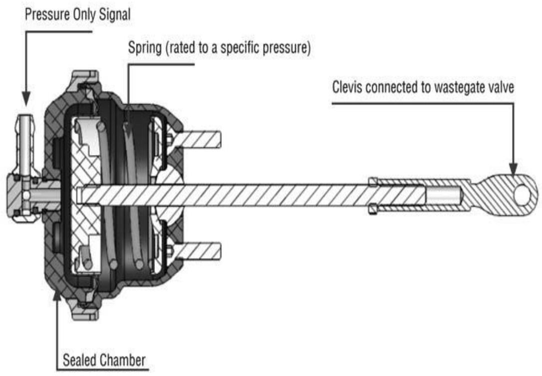

Fig. 4: Pneumatic Actuator

B. Determination of pressure and stroke length

Experimental setup has been carried out to determine the pressure and stroke length that is designed for the actuator. Pneumatic actuator inlet port is connected to the compressor line. Compressor input is controlled using a pressure control valve of range (Gauge) (0-2) bar. Pneumatic actuator rod is connected to Push type LVDT, based on its deflection, change in voltage is occurred. Results are displayed via scope and procedure is repeated again to reduce the instrument error.

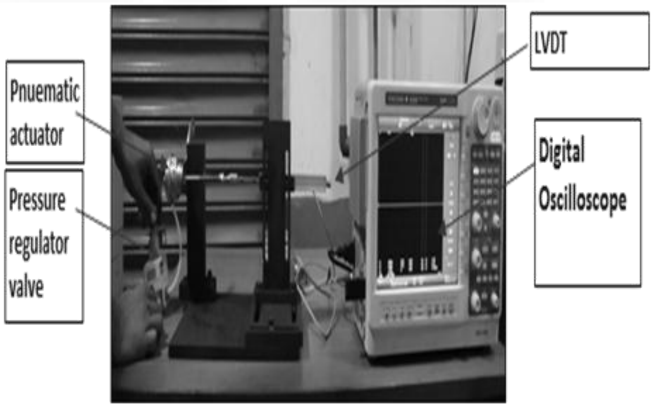

Fig. 5: Experimental Setup

The boost pressure and the stroke length for the various intermittent point are determined for the proposed actuator and it is allowed to be plotted in a graph which shows the results that the stroke length various up to 11mm and the pressure various up to 1.6 bar.

C. Dismantling the pneumatic actuator and determine the force exerted

Existing pneumatic actuator make use of compression spring and diaphragm to operate the valve. In this design the compression spring is preloaded to certain extend (40 mm).Hence for this 40 mm the force exerted is allowed to be determined which is the point form where the valve is allowed to be opened. And hence the fully loaded condition is determined and it will be the maximum stroke length.

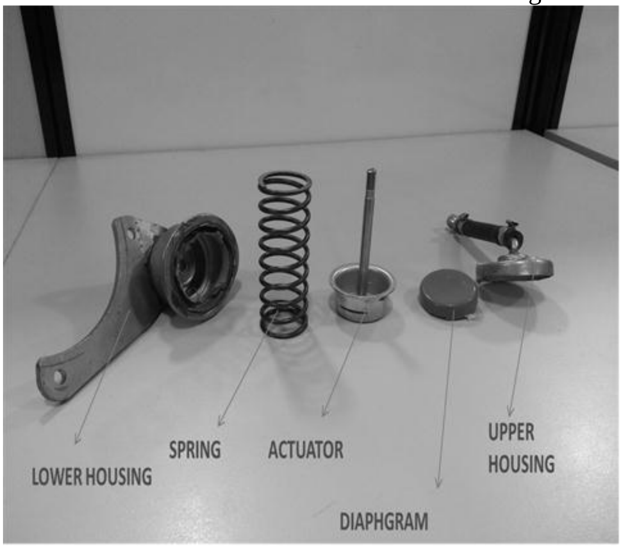

Fig. 6: Dismantled view of the Pneumatic Actuator

The spring used in the existing Pneumatic model is tested in the universal testing machine for which the force applied and the displacement for the respective forces is listed below.

- From the below graph it is concluded that the force acting lies between the range of 165 - 217.
- The stroke length is allowed to be varied from the 1-12mm.
- Force exerted is directly proportional to the stroke length.
- Pressure valve for the minimum boost pressure for low speed is .05 and the maximum boost pressure that can be achieved is .6 bar pressure.

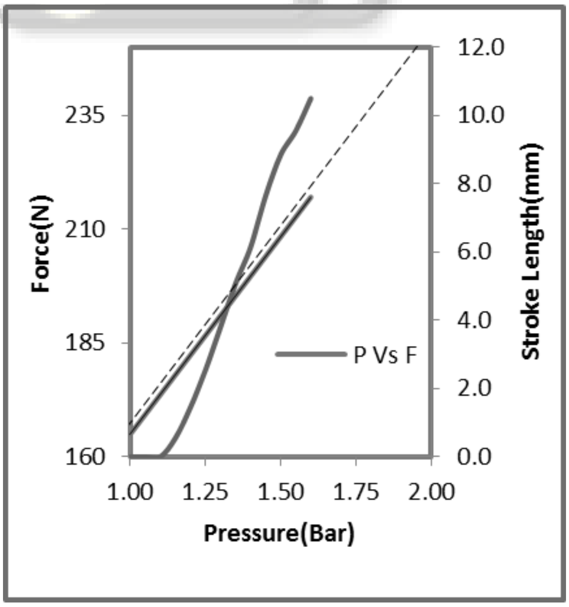

Fig. 7: Graph for pressure Vs. force and stroke Length

IV. DETERMINATION OF SPEED AND TORQUE

The force acting on the spring is transmitted along the actuator rod which in turn is utilized for valve opening and from the turbo charger the distance from the pivot end is measured and which in turn produces the torque at the pivot end in the various instantaneous points. The existing Pneumatic actuator response time is predicted as .1 sec for which the Stroke length is calculated. From which the speed of the valve opening at the pivot end is calculated for various points.

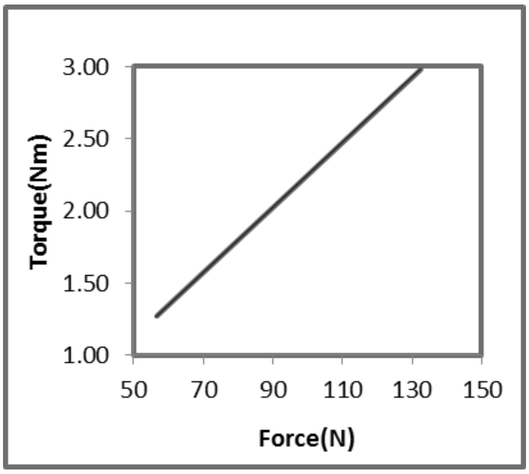

Fig. 8: graph for force Vs. torque

The linkage in the actuator end is transferred to the pivot end to open and close the valve . Opening of the valve is achieved by the torque acting on the valve and the retraction is achieved by the pre loaded torsion spring . But the spring also plays an another major role that it reduces the impact of vibration on the actuator.

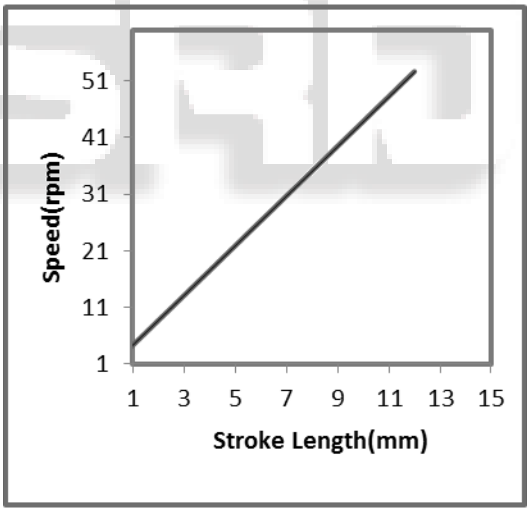

Fig. 9: graph for Stroke Length Vs. speed

The stroke length achieved for a time interval turns as the velocity of the rod. From which the angular velocity of the valve can be determined. Finally the speed of the pivot end is calculated for various intervals.

V. DETERMINATION OF MOTOR

To meet the specified speed and torque at the pivot end market research has been carried out on various aspects such as size weight and cost .From which a micro motor of two poles, 10 slots is selected. Its speed, torque and current curve calculated.

Design and calculation for various gear design layout are determined. Namely toothed belt, Spur gear , planetary gear, bevel gear, worm gear from which various combination has been carried out to meet the above mentioned motor specification. From which a worm a wheel arrangement has been finalized due to its better speed reduction and self-locking capacity. This replaces the work of the torsion spring on the existing model

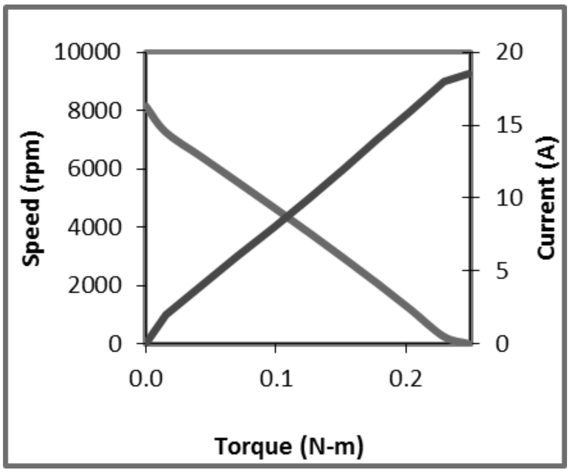

Fig. 10: Motor Specification

Gear/Gear Assembly Efficiencies:

	EFFICIENCY RANGE %	RATIO RANGE	PITCH LINE VELOCITY (FEET/MIN)	PITCH LINE VELOCITY (METERS/MIN)
SPUR	97 TO 99	1:1 TO 10:1	10,000	3,000
BEVEL	96 TO 98	5:1 TO 400:1	10,000	3,000
WORM	50 TO 90	5:1 TO 400:1	25,000	7,600
HELICAL	96 TO 98	1:1 TO 8:1	10,000	3,000

Fig. 11: Gear efficiency

VI. SELFLOCKING WORM AND WORM WHEEL

Worm and Worm Wheel are best choice of gearing when high drive reduction is required. A unique feature of Worm and Wheel assemblies is their ability to prohibit back driving. Certain pitches and leads of the worm will not permit the worm wheel to drive the worm. This is useful when an application requires the output to lock-up should the application operate in the opposite direction.

Worm and Worm Wheel assemblies must be mounted on perpendicular, non-intersecting shafts worm shaft. Unlike ordinary gear trains, the direction of transmission (input shaft vs. output shaft) is not reversible, due to the greater friction involved between the worm and worm-wheel, when a single start (one spiral) worm is used. If a multi-start worm (multiple spirals) then the ratio reduces accordingly and the braking effect of a worm and worm-gear may need to be discounted as the gear may be able to drive the worm.

Whether a worm and gear will be self-locking depends on a function of the lead angle, the pressure angle, and the coefficient of friction; however it is approximately correct to say that a worm and gear will be self-locking if the tangent of the lead angle is less than the coefficient of friction. For which appropriate gear ratio has to been determined.

VII. MODELLING OF ELECTRIC ACTUATOR

The model is created using proe crieo modeling software. The electric actuator for a waste gated turbo charger comprises of a motor, speed reducers , gear housing , outer cover ,output pivot. For the obtained speed , torque the motor model is designed which consists of yoke , magnet for rotation, lamination pack , insulation mould, brush box, it consists of a armature shaft where it act as a worm shaft provided with helical groove at one side.

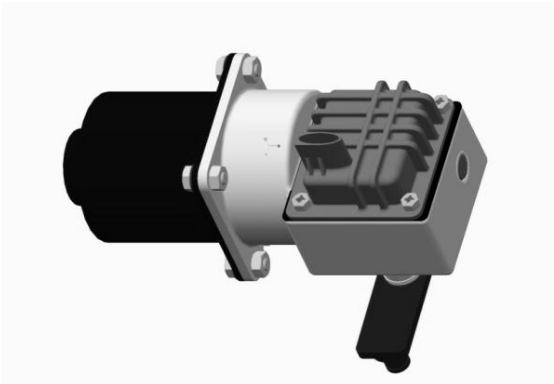

Fig. 12: electric actuator

To the worm shaft a sector worm gear is connect which is output part of the motor. The angle of valve opening is achieved by stopper provided on the side of the sector gear. To achieve a compact design a sector worm is preferred in case of wheel. Provision is provided for the circuit design and power supply to the motor.

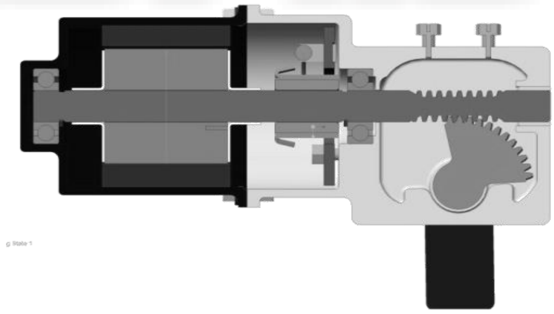

Fig. 13: cut sectional view of actuator

VIII. RESULT AND CONCLUSION

As it is evident from the discussion above, this is obviously an improvement over the existing pneumatic diaphragm actuators presently which is being used in many turbo chargers

- The waste gate can be opened and closed in precise increments to provide a smooth operation.
- The angle of valve opening can be manipulated as required, enabling the turbocharger to run at its maximum efficiency speed for most time.
- Quicker response to boost as well as waste gate valve opening will lead to better efficiency. A 10

times increase in response time is obtained when it is compared with the existing pneumatic actuator.

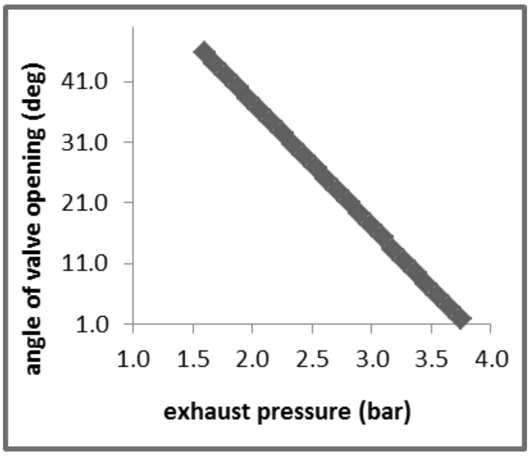

Fig. 14: graph Pressure Vs Angle

- The future scope of the project is to control the time required to open and hold the waste gate valve at open state using a controller.
- The controller will be supplied with the input parameters from the engine ECU which will be the engine load, engine speed and exhaust pressure with the help of sensors.

Acknowledgment

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