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ELECTRIC SERVOSYSTEM FOR TURBOCHARGER VACUUM ACTUATOR REPLACEMENT

This paper deals with electric compensation servo system which serves as an upgrade for existing turbocharger vacuum pressure regulation, particularly for low-volume engines. Proposed servosystem is suitable for variable geometry turbocharger (VGT) or variable nozzle turbocharger (VNT). Servo system comprises from control unit which is attached to the signal conditioner and to the microprocessor. The microprocessor controls the servo drive through the output amplifier and servo drive is mechanically connected to the turbocharger. Advantage of this upgrade is in better response to torque requirements from driver, especially in low engine speed.

INTRODUCTION

Nowadays, in modern so called "downsized" internal combustion engines, the automobile manufacturers use turbochargers to achieve higher power – to – volume ratio. Regardless of the problems associated with downsizing, the use of a turbocharger is suitable way to increase engine power. By using turbocharger, the engine power is increased by compressing intake air before entering the engine. Basically, the turbocharger is air pump driven by the engine's exhaust stream. The boost pressure affects the driver's experience. A fast response in boost pressure is advantageous. As the boost pressure is generated by the rotation of the compressor, the dynamic of the compressor speed is hypothetically faster than the dynamic of the boost pressure. With the implementation of a turbocharger position sensor and electronic actuator, it may give a faster feedback response to the controller and hence that it is thought to give a faster response and a more robust control. [1,2]

1. MODERN TURBOCHARGERS

Wastegate turbochargers

On a standard turbocharger (non-VGT), maximum boost pressure is controlled by a device called a wastegate. The wastegate is essentially a valve that can be internally or externally integrated into the turbine housing. When a predetermined boost pressure is realized, the wastegate opens and allows exhaust gases to bypass the turbine.

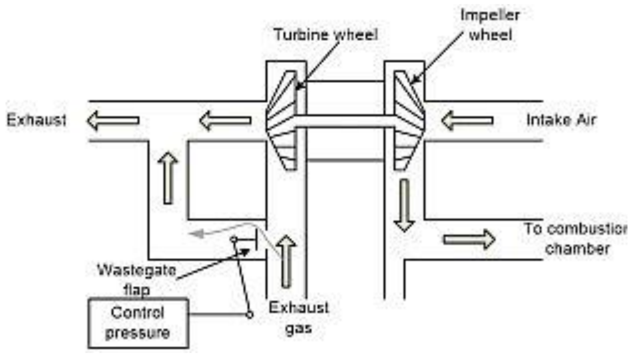

Fig. 1. *Vacuum wastegate turbocharger actuator*

In effect, the wastegate controls turbocharger outlet pressure by metering the amount of exhaust flow across the turbine. Exhaust gases that bypass the turbine housing expel directly into the exhaust system at the turbine outlet. [1,3]

Variable nozzle / variable geometry turbochargers

Since the late 1990s many diesel cars have been fitted with a Variable Geometry Turbocharger or Variable Nozzle Turbocharger. These turbochargers are very effective in minimizing the effects of turbo lag, resulting in a more responsive throttle especially at low engine speed.

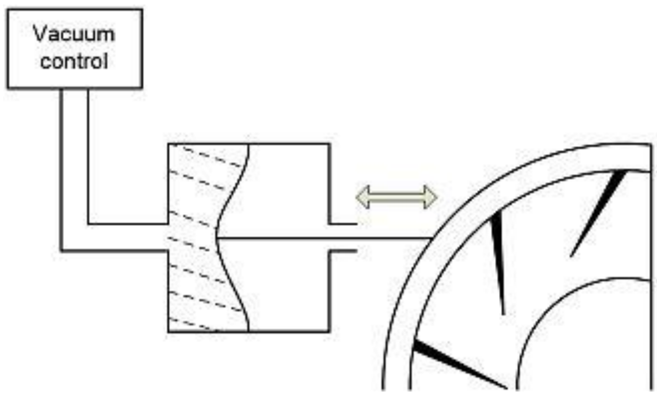

Fig. 2. *Vacuum variable nozzle turbocharger actuator*

These systems work by changing the speed and direction of the exhaust gases onto the turbine wheel. The most common of these systems is Garrett's VNT ® mechanism which incorporates a ring of small movable vanes around the turbine wheel. These vanes are often referred to as the speed control mechanism.

At slow engine speeds, the vanes are in the "closed" position narrowing the gap between them which effectively accelerates the exhaust gas onto the turbine wheel. At high engine speed the vanes open up slowing the exhaust gases, which stops the turbocharger from over-boosting. In most cases this level of control negates the need for a conventional wastegate. Despite these benefits, such turbochargers can be prone to problems. The speed control mechanism is easily affected by carbon build-up, which, if it becomes excessive, can cause the mechanism to jam. [3]

2. VARIABLE NOZZLE/GEOMETRY TURBOCHARGERS

Vacuum variable nozzle actuator

The low volume (up to 2000 cc) engines with turbocharger, uses vacuum actuator to control the turbo boost pressure- fig. 3. The disadvantage of such solution is the absence of a closed loop control (feedback), and the resulting fluctuations in tensile force of vacuum actuator according to the system negative pressure. System pressure fluctuates in the range from -0.6 to-0.9 bar.

The system described in this paper can be used to replace the standard vacuum actuator at comparable cost. Furthermore, novel control system of electric actuator increases the efficiency of the entire management system and turbocharger and reduces emissions of turbocharged internal combustion engine. [2]

Fig. 3. *Vacuum turbocharger actuator*

Electric variable nozzle actuator

Unlike the VNT system with vacuum regulation, VNT with electric regulation contains worm gear. This mechanical system eliminates the feedback effects from the exhaust gases to the turbocharger. Electronically controlled turbocharger is mainly used for more than 4 cylinder engines with higher volume and performance. Other application of electrical control of the turbocharger is in the system of the two turbochargers (i.e. Bi-turbo). [3]

Electric actuator for control of variable nozzle turbocharger uses PWM signal for control of angle of vanes in input nozzle of turbocharger. The control algorithm in electronic control unit of the car is different, due to fact that, electric servosystem uses DC motor to control of position (angle) of the vanes in the turbocharger – fig. 5. Due to this fact it is not possible to interchange vacuum actuator and electric actuator without further modifications.

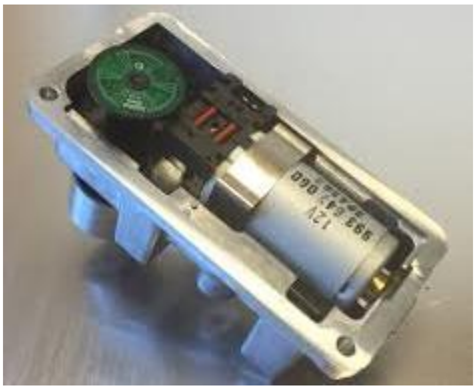

Fig 5. *Electric turbocharger actuator*

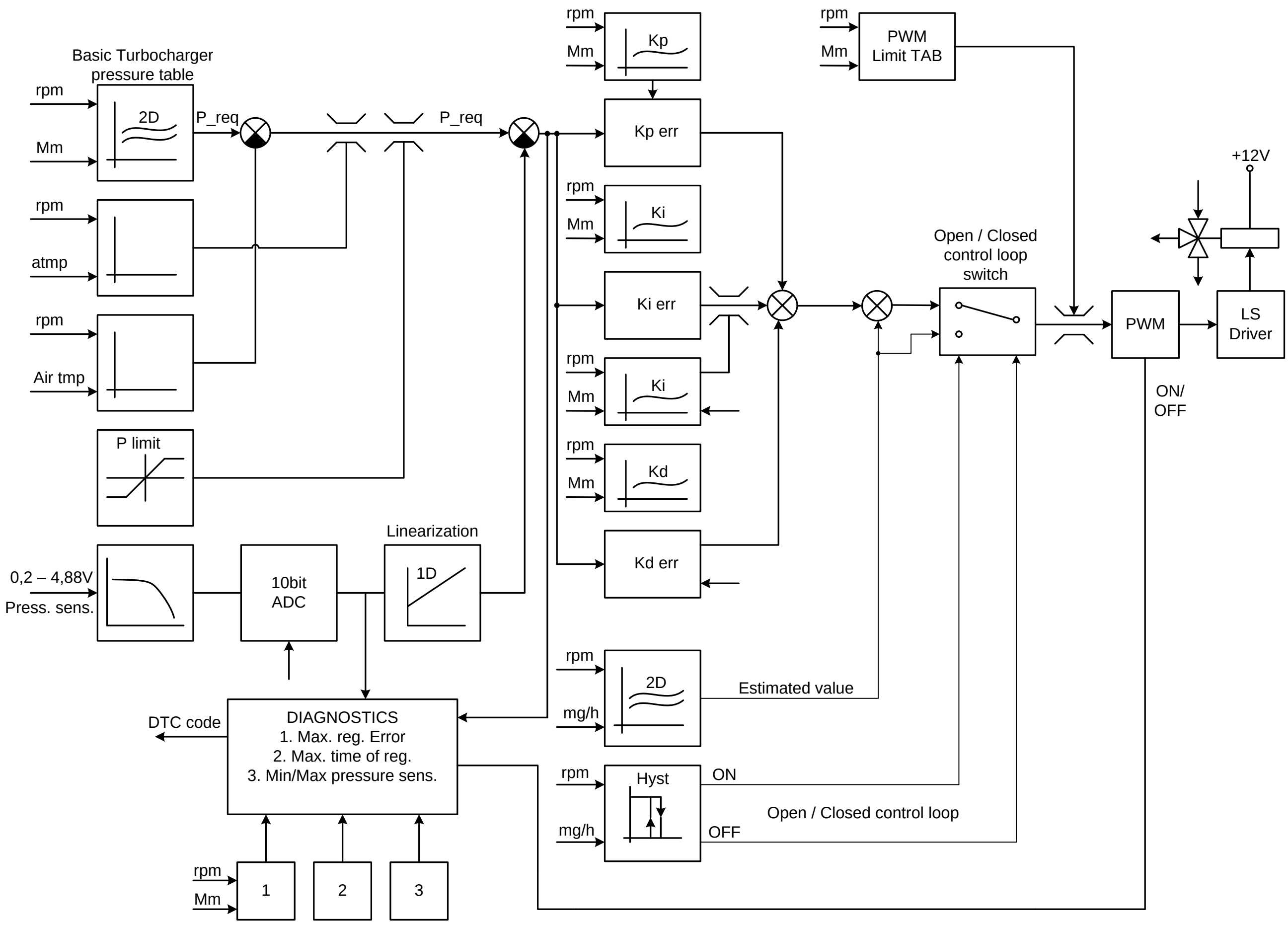

Fig. 4. Control algorithm for VNT turbocharger

3. CONTROL OF TURBOCHARGER ACTUATORS

Block diagram of control system for standard variable nozzle actuator is shown on figure 4. This control algorithm is implemented in electronic control unit (ECU) and as input values uses data from engine sensors. The basic logical element of his control system is ON / OFF switch, which switches the system from regulation in open loop to closed loop regulation. At low rpm and low load (cruising speed at outside road), the system operates in open loop and the values of PWM for control of vacuum actuator and subsequently the nozzle of turbocharger, are obtained from a 2D array. When increasing the load (acceleration), the system switches to control in closed loop, when variations in control deviation are eliminated by using a PID controller. Output from ECU is PWM signal, which is connected to vacuum actuator and through mechanical connection controls the angle of vanes. [4]

Control of electric servosystem

Due to fact, that electric servosystem for vacuum actuator replacement is suitable for all types of cars and all VNT vacuum actuators; its control system uses the standard output values from ECU.

Electric servosystem for turbocharger vacuum actuator replacement, which is described in this article, works on a similar principle as an electric regulator of VNT, but it can be applied to the VNT system with the vacuum control. This implementation allows the use of a separate microprocessor with its own regulatory structure. By use of microprocessor with additional control algorithm, allows the implementation of an electric servosystem in each of vacuum controlled turbocharger without any mechanical adjustments. [3,4]

As mentioned above, in standard vacuum actuator, the electronic control unit (ECU) generates the PWM signal for controlling of the solenoid 3 – way valve, which modifies position of vacuum actuator. Most significant difference between standard vacuum VNT control and proposed electric servosystem control is in regulation structure. Standard vacuum control is based on closed loop to control pressure in the turbocharger (see fig. 4). Due to mechanical simplicity of vacuum actuator, this system does not use the information about position of the actuator. [5]

Electric servosystem uses closed loop to control the position of DC motor and thus regulates the pressure in turbocharger. In control algorithm, the output from ECU is used as input value. The level of the control signal is modified from 12V to 5V through antiflicker systems (Schmidt flip-flop circuit). The signal from ECU is connected to input systems of IC where the leading and falling edge of the signal is sensed. This system with modifications mentioned above is independent on engine control frequency. In the case of signal error, the internal timer overflows, which leads to setting of overflow flag in processor. After setting the overflow flag, the servosystem is set to start position due to protection of turbocharger. Signals from IC are evaluated by the equation 1. [2]

$$DUTY = \frac{IC1}{IC1 + IC2} * 1000 \qquad (1)$$

The signal is furthermore processed by moving average with 16 samples.

$$MA = \frac{p_M + p_{M-1} + p_{M-2} + \ldots + p_{M-(n-1)}}{n} = \frac{1}{n}\sum_{i=0}^{n-1} p_{M-i} \qquad (2)$$

Where n is number of samples.

After processing of the signal, next step is limitation of derivation of position θ with time. Limitation of dθ/dt by limiter increases the lifetime of servosystem by several times. Limitation eliminates the Kd constant of controller. This elimination of constant Kd, does not influence the dynamics of servosystem, due to considerably shorter time constants compared to vacuum controlled servosystem. After modification, the signal is processed in microprocessor by look-up table and converted to duty cycle. [2,5]

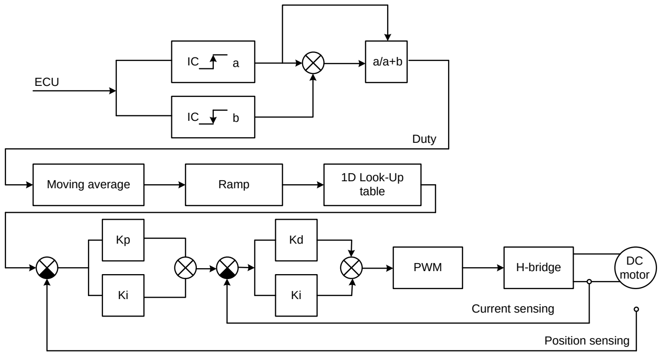

Fig.6. *Control diagram of electric servosystem*

Requested value of position (position of servosystem solenoid) enters the PI controller with parallel control structure. Output from the PI controller is control current of DC motor in servosystem. Value of the transfer function of speed controller is near 1, due to fast dynamics of position control.

4. PERFORMANCE MEASUREMENT

After implementation into 16bit microprocessor S12 from NXP, the car with vacuum actuator and electric servosystem was compared. The measurement was made on electromagnetic 4x4 automotive brake MAHA, with maximum power 4x270 kW. First measurement was made with standard vacuum actuator. From the fig.7 is clear that absence of closed control loop for position leads to over and under regulation of pressure in turbocharger (requested value is 2,350bar). [2]

Fig.7. *Measurement – engine with vacuum actuator*

From the fig. 8 is clear that use of electric servosystem with proposed control structure eliminates the steps in the turbocharger pressure and increases the power of the engine. Most significant difference is in the shifting of torque curve, where nominal torque is shifted to lower rpm, thus the engine works at lower rpm and the NOx emissions are reduced. [2]

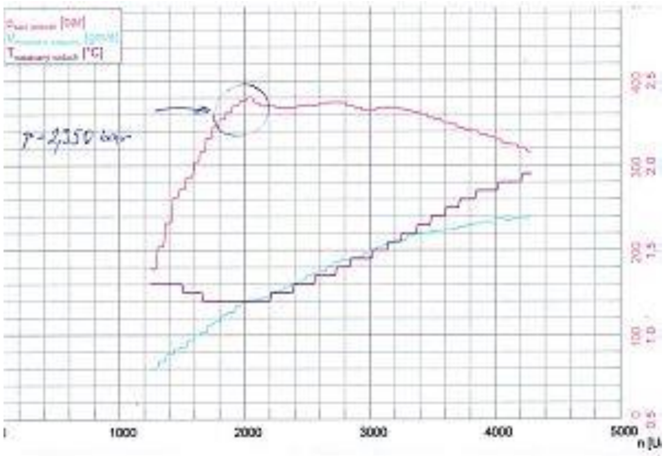

***Fig. 6.** Measurement – engine with electric servosystem*

CONCLUSION

The paper shows possibility of replacement of standard vacuum actuator for variable nozzle/geometry actuator by electric servosystem with microprocessor. Use of this servosystem with novel control algorithm reduces the emissions from engine, increases the power of the engine and eliminates the vacuum actuator. Other advantage of this system is in elimination of negative pressure source from turbocharger system (proposed servosystem is powered by standard 12V board network). The only disadvantage of proposed electric servosystem is necessity for calibration between control system (microprocessor) and turbocharger.

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Servosystem elektryczny dla urządzenia zasilającego pasażenia turbowego

W pracy przedstawiono możliwość wymiany standardowego siłownika próżniowego dla siłownika o zmiennej dyszy / geometrii za pomocą elektrycznego serwomechanizmu za pomocą mikroprocesora. Korzystanie z tego serwosu w nowym algorytmie sterowania zmniejsza emisje z silnika, zwiększa moc silnika i eliminuje siłownik podciśnieniowy. Inną zaletą tego systemu jest wyeliminowanie źródła ujemnego ciśnienia z systemu turbodoładowania (proponowany serwoster jest zasilany standardową siecią 12V). Jedyną wadą proponowanego elektrycznego serwosysu jest konieczność kalibracji pomiędzy systemem sterowania (mikroprocesorem) a turbosprężarką.

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