

Development of an Auto Throttle System for High-Pressure Washer Engines

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ABSTRACT

An Auto Throttle system for residential high-pressure washer (HPW) engines has been developed. During periods of non-loaded use, engine speed is reduced from 3850 rpm to 2500 rpm.

A residential high-pressure washer has two modes, loaded (the operator is using the spray wand) and unloaded (the operator is not using the spray wand). Compared to the base model, in an unloaded condition, the Auto Throttle control system achieves a noise level reduction of 9 dB(A). The fuel economy is increased by 43%, overall carbon dioxide emissions are reduced, and engine and pump life are enhanced. User fatigue is reduced through a reduction of initial spray wand reaction force.

1. Introduction

One of the Honda philosophies is the continuous enhancement of products through economic, ecological, and ergonomic characteristics. Launched in 1997, the Honda GC series (GC Horizontal crankshaft, GCV Vertical crankshaft) engines are the highest sales volume Honda general purpose engine for consumer usage. In the late 1990s, residential high-pressure

washers became very popular. Consequently, sales of the GCV engine increased and today the majority of GCV engines are used in the residential high-pressure washer (HPW) market. The Auto Throttle system for the GCV engine was launched to U.S. customers in March 2010. Figure 1 shows the first application for the Auto Throttle engine on a residential HPW with an illustration of the Auto Throttle control system and its location.

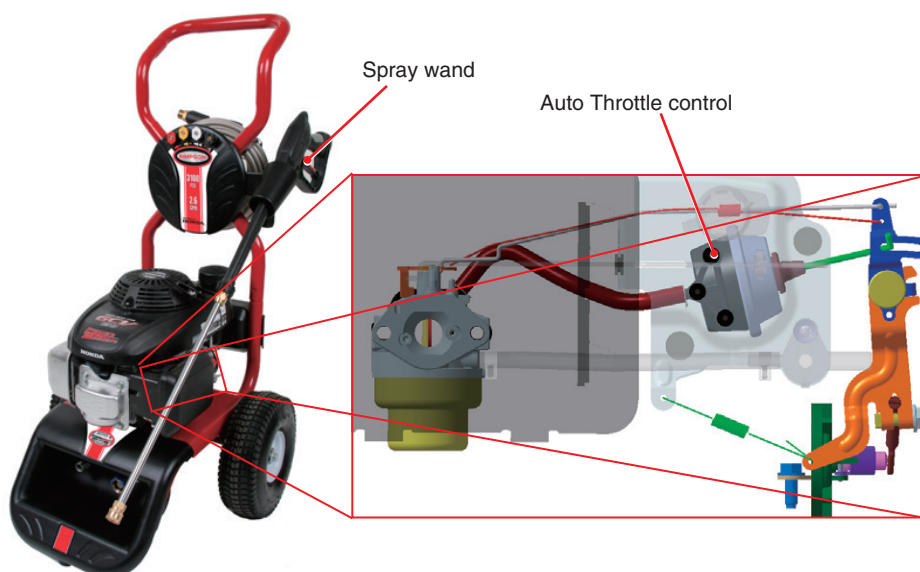


Fig. 1 High-pressure washer unit with Auto Throttle system

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Table 1 Honda GCV190 engine specifications

Engine type	Air-cooled 4-stroke OHC single cylinder
Bore x stroke	69 x 50 mm (2.7 x 2.0 in)
Displacement	187 cm ³ (11.4 cu in)
Compression ratio	8.5 : 1
Net horse power output	3.8 kW (5.1 HP) at 3,600 rpm
Net torque	11.3 Nm (8.3 lbs ft) at 2,500 rpm
Ignition system	Transistorized magneto
Dimensions (L x W x H)	367 mm (14.4 in) x 331 mm (13.0 in) x 349 mm (13.8 in)
Starting system	Recoil or electric starter
Carburetor	Horizontal type butterfly valve
Lubrication system	Forced splash
Oil capacity	0.55 l (0.58 US qt, 0.48 Imp qt)
Fuel tank capacity (liter)	0.93 l (0.98 US qt)
Dry weight	12.5 kg (27.6 lbs)

2. Throttle Control for the Base High-Pressure Washer Engine

Table 1 shows the specifications for the Honda GCV190 engine, which is the base engine for the Auto Throttle system. The engine has two modes of operation, loaded and unloaded. Loaded mode is when the user has activated the spray wand and the HPW pump is in its full-flow, high-pressure setting. The unloaded mode is when the spray wand is released. This causes the pump to re-circulate in a bypass function and the engine load decreases 90%. The base engine control, shown in Fig. 2, uses a mechanical centrifugal governor system with a balancing spring to regulate the throttle's position. Engine speed is fixed and the typical HPW setting is 3600 rpm. The inherent characteristic of this type of control is to increase the engine speed when the engine load is removed. On average, this increase is 250 rpm above the load set point. When the engine is idling at 3850 rpm, it is noisy, unnecessary fuel

is being consumed, and there is more engine wear. The Auto Throttle control system decreases these characteristics.

3. Auto Throttle Control for GCV High-Pressure Washer Engine

The fundamental purpose of the Auto Throttle control system is to sense an engine load demand. In the beginning of the development, five goals were set: reduce noise, reduce CO₂, minimize cost impact, increase component life, and create an automatic, self-contained system.

Figure 3 shows the components of the Auto Throttle system. The exclusive components developed for this system include a vacuum diaphragm and pivoting governor arm. Their function is to provide load-sensing feedback. Other contributing components include a centrifugal governor and supporting governor spring, a throttle return spring, and a ported carburetor insulator.

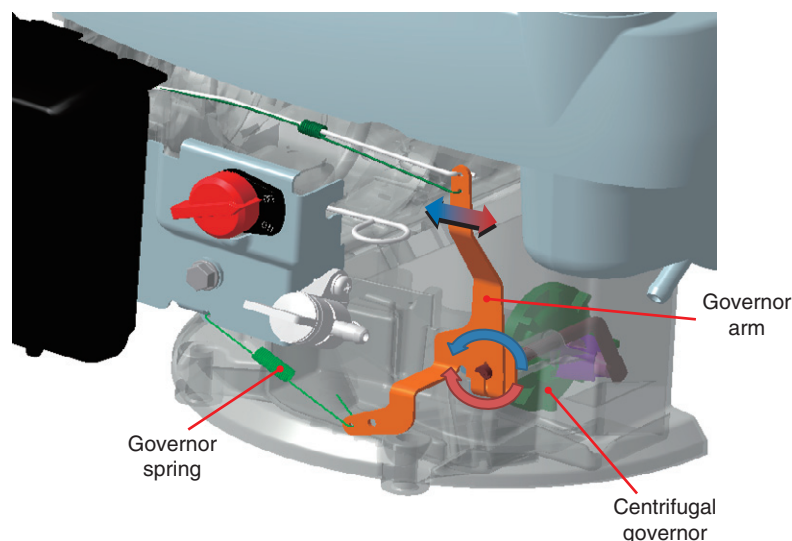


Fig. 2 Fixed Throttle control of GCV engine

3.1. Operation Cycle

Figure 4 shows the main operation cycle and noise level of a HPW using both the base fixed throttle and Auto Throttle systems. When the engines are loaded, the performance is the same. But when the spray wand is released and there is no pump demand, the base engine increases engine speed while the Auto Throttle system reduces it.

3.2. Parts Function in the Auto Throttle Control System

3.2.1. Vacuum Diaphragm

Figure 5 shows a cross-sectional view of the diaphragm assembly. The function of the diaphragm is to convert engine vacuum into a mechanical force to close the throttle. Manifold vacuum pressure is supplied to the diaphragm through the ported

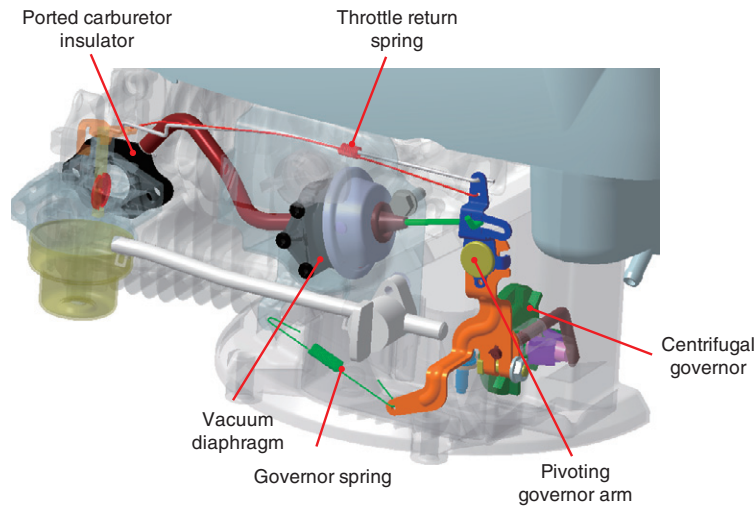


Fig. 3 Auto Throttle system components

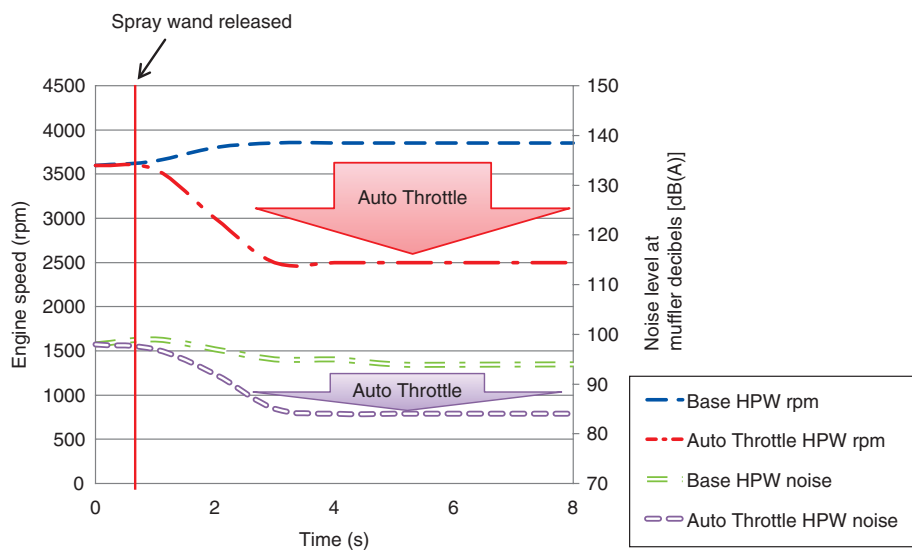


Fig. 4 Comparison of base engine and Auto Throttle engine noise

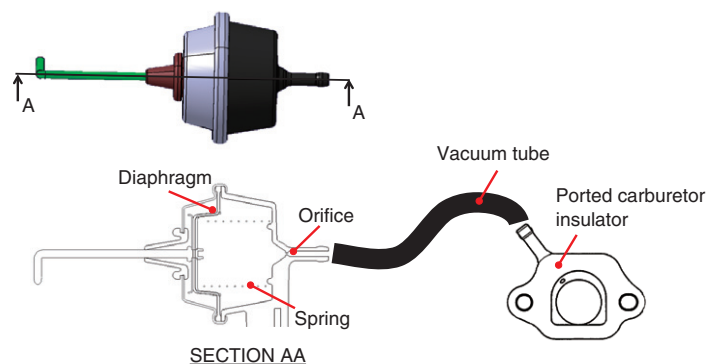


Fig. 5 Vacuum diaphragm construction

carburetor insulator. As the engine load decreases, the internal manifold vacuum increases. When manifold pressure reaches approximately -6.6 kPa, the diaphragm begins to close the throttle. Diaphragm force is affected both by its stroke position and by the vacuum pressure signal of the engine intake. Since the application is a single cylinder engine, the vacuum pressure is always pulsating, which is undesirable for system stability and durability. Therefore, an orifice was added in the diaphragm inlet to reduce the pressure fluctuations inside the diaphragm body. The orifice diameter and diaphragm body volume have inverse effects on the pressure fluctuation and response time. By reducing the orifice diameter or increasing the diaphragm body volume, it is possible to reduce the pressure fluctuation within the diaphragm.

However, these changes also influence the response time of the engine. Once body volume was determined based on force requirements and packaging space, the orifice diameter was optimized through testing. Figure 6 shows a portion of the test results.

3.2.2. Centrifugal Governor

The centrifugal governor's primary purpose is to regulate engine speed at the rated load of the engine. As shown in Fig. 7, as engine speed increases, the centrifugal governor closes the throttle. The rotational movement is provided by the engine crankshaft. As the engine speed increases, the flyweights swing out and push the slider. The slider then generates a moment on the governor shaft that closes the throttle. The speed at which the centrifugal governor maintains steady

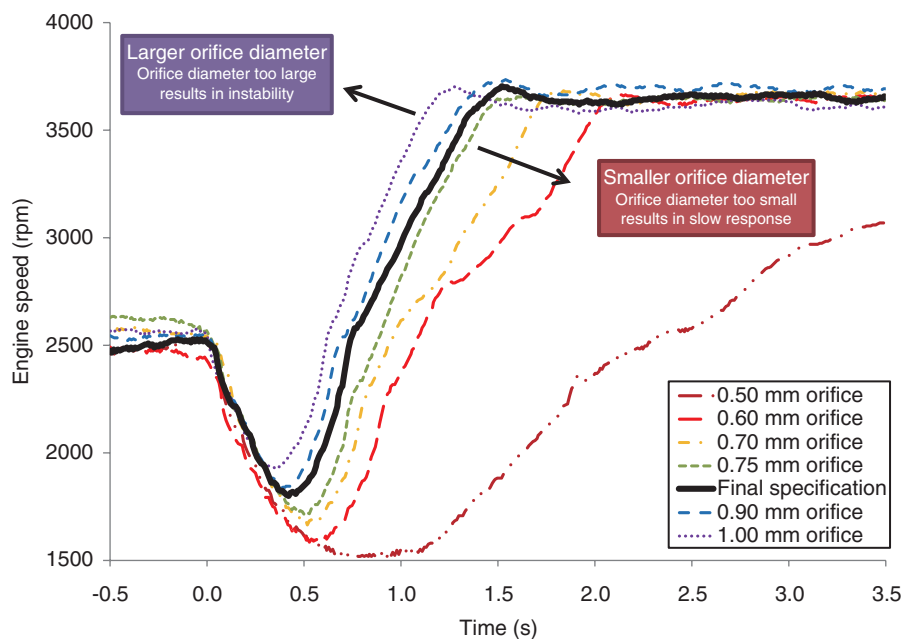


Fig. 6 Orifice effect on system response time

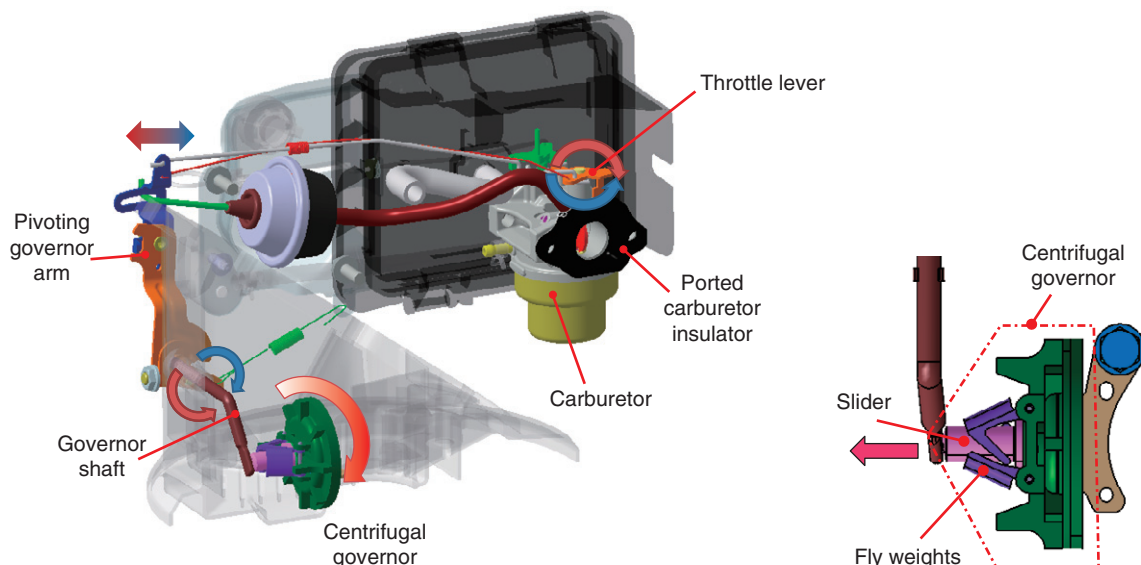


Fig. 7 Centrifugal governor configuration

state is balanced by the governor spring. Typical HPW setting is 3600 rpm while loaded. The centrifugal governor is unchanged from the base engine.

3.2.3. Pivoting Governor Arm

The governor arm's role in the system is to function as connection between input forces and regulation of throttle position. As shown in Fig. 8, the arm receives input from the centrifugal governor (F_G), diaphragm (F_D), governor spring (F_{GS}), and throttle return spring (F_{TS}).

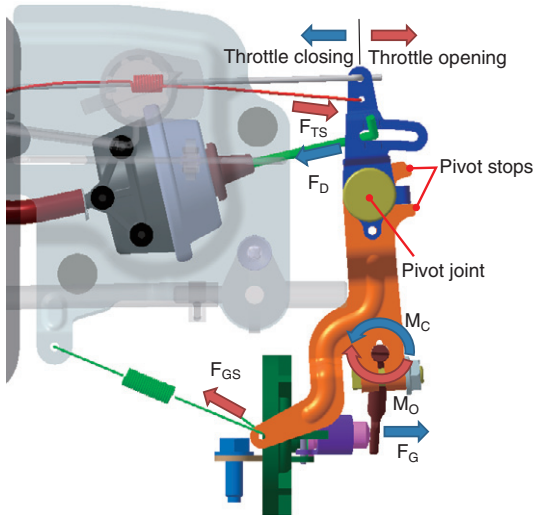


Fig. 8 Pivoting governor arm force summary

A governor arm pivot was created to alter the moment induced by the governor springs when the engine is idling. The force of the governor spring is relatively high, and adding a pivot joint to the governor arm allowed the force required of the diaphragm to be smaller in comparison, thus reducing its overall size. The pivot allows a change in throttle position to be isolated from the governor shaft. As shown in Fig. 9, the optimum pivot travel was determined through testing. If the pivot angle is too great, the engine will not return to high speed from idle; if the pivot angle is too small, the engine is not stable in the idling condition.

3.2.4. Governor and Throttle Return Springs

Figure 3 shows the governor spring and throttle return spring. The governor spring is critical for maintaining the proper engine speed when the engine is loaded; therefore, it was important to maintain the basic spring design from the base engine. Early in development, testing showed that this spring generated a moment that was too strong when the engine was idling, so it was not possible to balance the system to operate correctly in both idle and high-speed conditions without changing the base engine governor system. The governor arm pivot joint was added to keep the base engine governor spring and maintain a small diaphragm package. Consequently, a stronger throttle return spring was required to overcome the friction of the governor arm pivot joint.

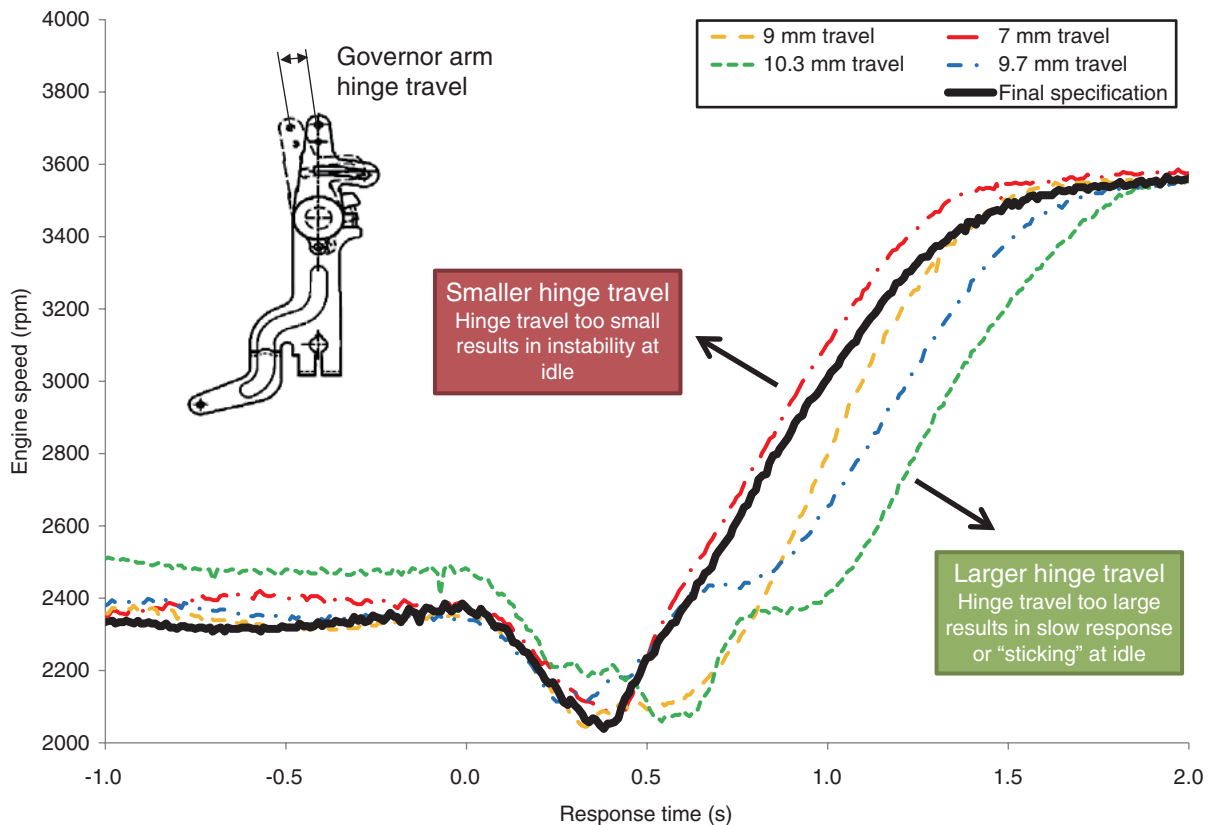


Fig. 9 Governor arm performance

4. Basic System Configuration

There are four forces that work to regulate the throttle position of the engine. As shown in Fig. 8, the diaphragm (F_D) and centrifugal governor (F_G) create a moment about the governor shaft that controls the closing of the throttle. The governor spring (F_{GS}) and throttle return spring (F_{TS}) create a moment about the governor shaft that controls the opening of the throttle. If the opening moment is too long, the engine cannot idle properly. If the moment is too short, the engine cannot return to high speed when idling. Figure 10 depicts graphically the Auto Throttle system controlling the engine speed. From $t = -1$ to 0 , the throttle close moments ($F_G + F_D$) are longer than the open moments ($F_{GS} + F_{TS}$). At $t = 0$, the spray wand is activated, the engine load increases, and the vacuum signal weakens. During this transition from idle to high speed, the open moments overcome the close moments and the engine speed is then solely regulated by F_G and $F_{GS}+F_{TS}$. From $t = 2$ to 7 , the engine operates at rated load. Rated load for the GC series engine varies from 50% to 80% throttle opening depending on the application. At $t = 7$, the spray wand is again released. As the engine load is removed, the engine speed immediately increases, the throttle plate closes, the vacuum signal builds again, and F_D overcomes F_{TS} initially. As the engine speed

is decreasing, F_{GS} and F_G also decrease, F_D pulls the throttle plate closed, the engine vacuum stabilizes, and the system is balanced at idle.

5. Performance Evaluation

5.1. System Design Verification

In order to determine an appropriate system response time, a survey was conducted using several Auto Throttle engines that were modified to exhibit differing response characteristics when the spray gun was engaged and released. Actual HPW customers participated in the survey and provided feedback on the response characteristics. Based on the results, a maximum response time criteria was determined for transient conditions when spraying water and not spraying water.

In the final product, any factor that changes the engine output power, which includes engine temperature, engine friction, air-fuel ratio, and barometric pressure, also affects vacuum pressure. Other factors that affect system operation include pressure washer pump load part tolerance, manufacturing variability, and assembly. To guarantee the final performance of the Auto Throttle system, machines were built in “worst-case” configurations and verified to meet the design criteria. Figure 11 shows the testing results.

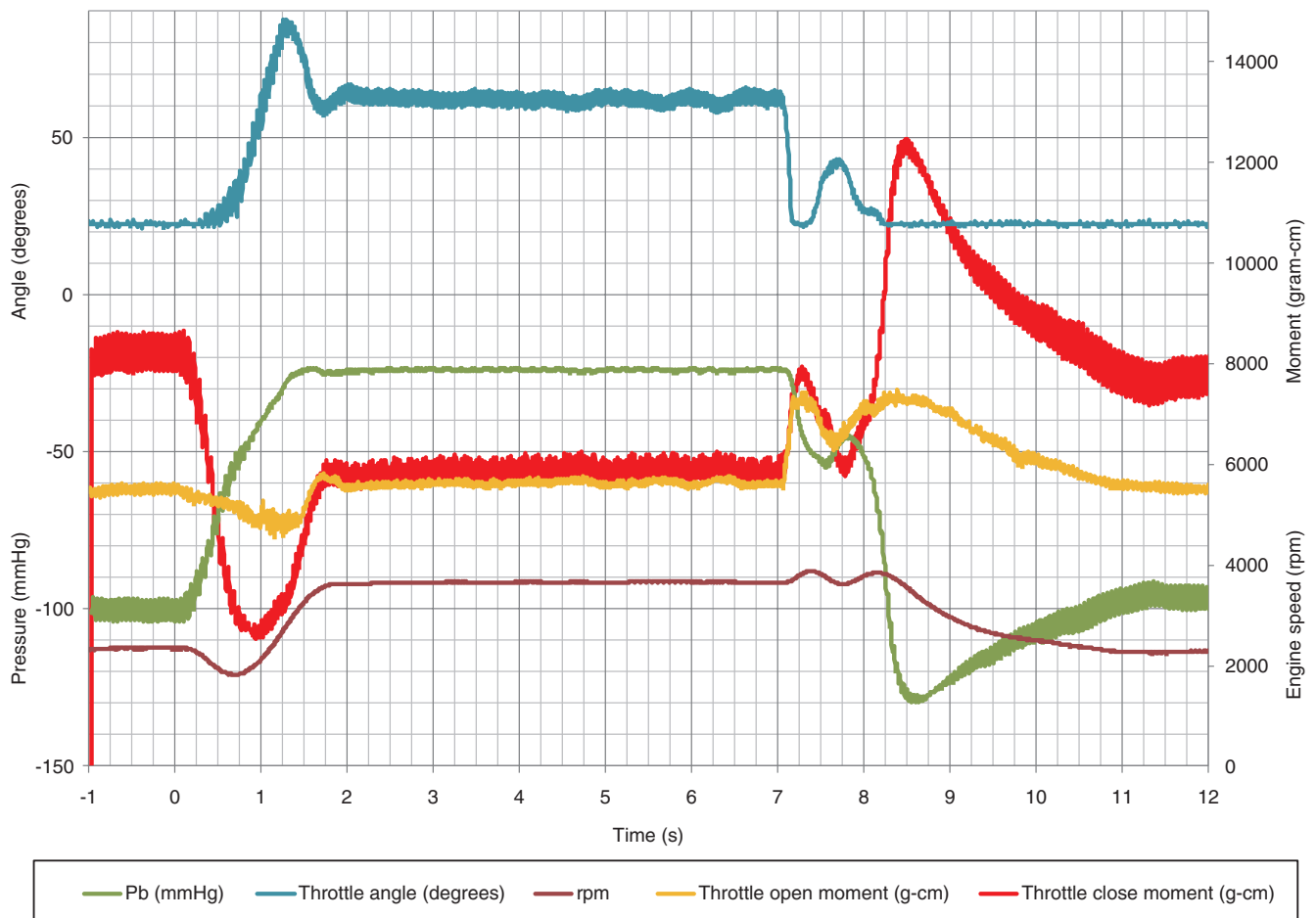


Fig. 10 Overall system performance

5.2. Noise and Fuel Consumption Enhancement

Two goals in the development were reducing noise and fuel consumption. The achievement level was determined by running the engine in high and low idle conditions and measuring the differences. The sound pressure level was measured in a hemi-anechoic chamber following the guidelines described

in ISO11094⁽¹⁾. Fuel consumption was measured by applying a steady load with a dynamometer and using a gravimetric flow meter. The loading conditions during these tests were set based on the typical loading applied by a HPW pump. Figure 12 shows the testing results.

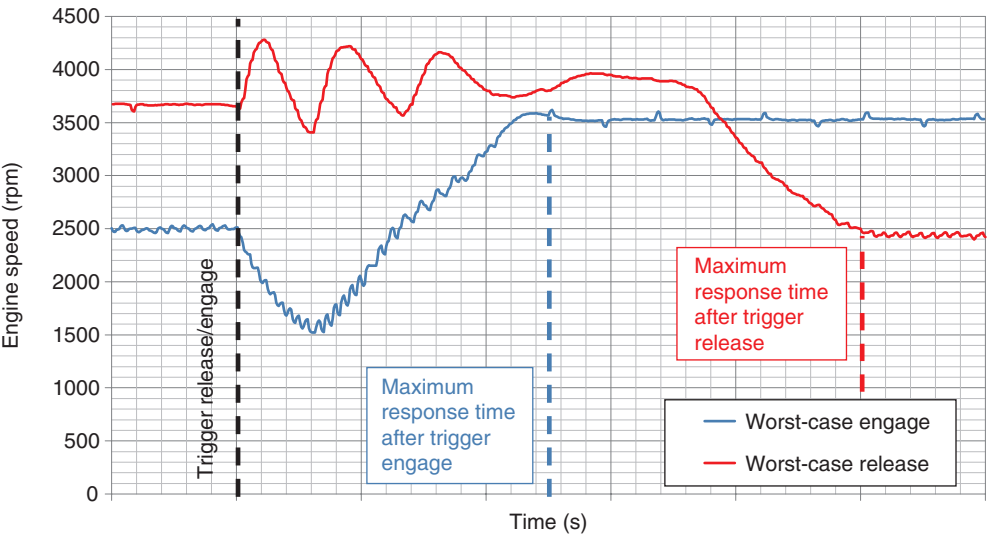
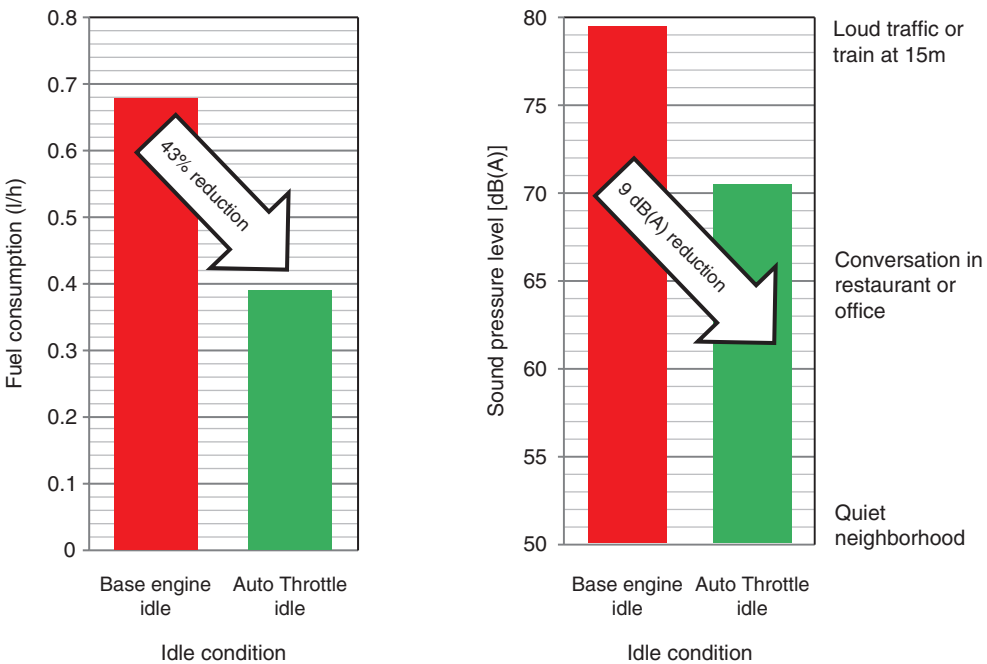


Fig. 11 Load on and off response time limits



Test condition

	Engine speed (rpm)	Load (Nm)
Auto Throttle idle	2500	1.15
Base engine idle	3850	0.95

Fig. 12 Noise and fuel consumption achievements

5.3. Spray Gun Force Reduction

Another benefit of the Auto Throttle system controlling a HPW engine is the reduced level of reaction force (or recoil) that occurs when the operator activates the spray wand. The initial engine speed and water flow are less than the base model HPW; therefore, the operator does not have to apply as much force to counteract the recoil caused by water exiting the wand. Instead, the reaction force builds gradually as the engine speed increases. This force transition was measured by supporting the HPW spray wand with a load cell and recording the force generated when the wand is activated on a base model engine and an Auto Throttle engine. Figure 13 shows the test results.

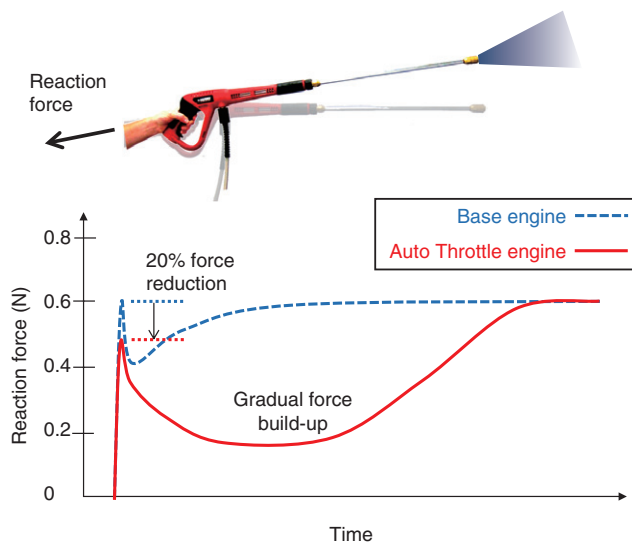


Fig. 13 Operator initial force

6. Conclusion

The Auto Throttle system accomplished the five development goals. The noise level of the engine in its idle state was reduced by 9 dB(A). This achievement is a result of reducing base engine speed from 3850 rpm to 2500 rpm using the Auto Throttle system. CO₂ emissions from the engine in its idle state were reduced. The emission reduction was confirmed by measuring the change in fuel consumption while the engine is idling. Idle fuel consumption was reduced by 43%. The system surpassed the initial cost reduction target by using common components between the base and Auto Throttle models. By reducing the engine idle speed, the Auto Throttle system achieves a 35% reduction in pump and engine revolutions in the idle state. Using engine vacuum as the actuation mechanism, the Auto Throttle system can automatically control the idle speed; no activation or adjustments by the operator are necessary.

In addition to the initial goals, the Auto Throttle system also achieved a reduction in user fatigue. This

was accomplished by a 20% reduction in the initial reaction force that the operator must support when the spray wand is activated.

The Auto Throttle system is an industry first, fully autonomous throttle control for a residential HPW. A patent application has been submitted for the achievement method of the Auto Throttle system. Currently, this type of control is being considered for other applications.

References

- (1) Acoustics — Test code for the measurement of airborne noise emitted by power lawn mowers, lawn tractors, lawn and garden tractors, professional mowers, and lawn and garden tractors with mowing attachments. ISO 11094:1991(E). Geneva, Switzerland: ISO, 1991.

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