

Design and Operation of a Brake and Throttle Robot

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ABSTRACT

This paper describes the design and implementation of the SEA, Ltd. Brake and Throttle Robot (BTR). Presented are the criteria used in the initial design and the development and testing of the BTR, as well as some test results achieved with the device.

The BTR is designed for use in automobiles and light trucks. It is based on a servomotor driven ballscrew, which in turn operates either the brake or accelerator. It is easily portable from one vehicle to another and compact enough to fit even smaller vehicles. The BTR is light enough so as to have minimal effect on the measurement of vehicle parameters. The BTR is designed for use as a stand-alone unit or as part of a larger control system such as the Automated Test Driver (ATD) yet allows for the use of a test driver for safety, as well as test selection, initiation, and monitoring.

Installation in a vehicle will be described, as well as electronic components that support the BTR. Operational modes and controls will be examined, followed by testing and results. The paper will close with an evaluation of the BTR and a brief view of possible future avenues of development and testing.

BACKGROUND

There is a need for a brake and throttle actuator in automotive and light truck testing. Properly designed, such a device can provide more consistent and

repeatable actuation and test results than a human driver, and can be used in tests that are beyond the capabilities of a human driver or where safety concerns preclude the use of such a driver.

A number of existing studies detail the development of automotive brake controllers, but none of them feature the portability and ease of adaptation necessary for the flexible testing of a variety of vehicles. Many studies, such as [13], implement brake control via alternate actuators that bypass the mechanical pedal linkages by directly controlling the brake fluid pressure. Others employ the vehicle's brake system and linkage, but still require significant and permanent vehicle alteration [11,12].

The BTR featured herein is the second version to be built and tested. An earlier version was part of an automated test driver project and performed well [2,4]. The second version was designed to have the same functionality, portability, and light weight of its predecessor as a stand-alone unit or as part of an automated test driver or similar device, and therefore borrowed much of the design from the first version.

DESIGN AND DEVELOPMENT

The design of the first version of the BTR began with a survey of many vehicles. Locations and angles of pedals, accelerator pedal force requirements, and potential mounting methods were looked at for passenger cars, SUV's, and pickup trucks. The first

version of the BTR used a servomotor to drive a precision ballscrew. Depending on its direction of rotation, it operated either the brake pedal or accelerator pedal through mechanical linkages attached to the pedals.

Though this first version performed well, there was a desire for increased performance, and some upgrading was required to better optimize the BTR. The second version has increased force capacity, faster application of force, increased durability, and the ability to directly measure the component of force applied normal to the brake pedal. These goals were achieved by retaining the same basic servomotor and ballscrew design of the earlier version, while modifying existing features and adding additional features as required to upgrade the unit.

Guiding these design goals were criteria enabling accurate adherence to a vehicle speed profile as well as the specifications from various SAE test standards. One instance of the latter type is the SAE Service Brake Structural Integrity Test Procedure [10], which stipulates that brake pedal force be ramped from zero to 200 lb at a rate of 2500 lb/s. Another example is the standard brake burnishing procedure associated with many SAE tests (e.g., [9]) which requires two hundred 40-0 mph stops at 12 ft/s² deceleration (a tiresome exercise that few human drivers can accurately maintain).

Specifically, the design goals for the current version BTR were as follows:

1. Capacity for 200 lb (890 N) of force perpendicular to the brake pedal.
2. Capacity for brake application time of 0.25 seconds at full rated load.
3. Not more than 20 lb (9 kg) of weight in the main base component.
4. Electrical limitations of 35 amps at 72 volts.
5. The unit should be able to be installed in a vehicle in about 30 minutes.
6. The unit should be fail-safe in case of electrical shutdown. If the power fails the throttle goes to idle and the brakes are applied.
7. The driver can override the system at any time.
8. The driver can sit in the vehicle in the normal position.
9. Position feedback control on the throttle, and force or position feedback control on the brake.
10. Algorithms for vehicle speed control.

The force, speed, and size specifications (1-4 above) are a function of the motor size and hardware configuration. BTR's with different actuation capacities could be designed and built using different motors and minor hardware modifications.

The BTR is shown mounted in two different vehicles in Figures 1 and 2. The basic layout of the BTR mechanism is shown in Figure 3. A servomotor drives a ½ inch (12.7 mm) ballscrew. The ball nut moves laterally in the vehicle. Attached to the ballnut is a plate that acts as a face cam. At the cam's neutral position, neither the throttle nor the brake is applied. When the ball nut and face cam move to the right, the throttle is applied through the action of a lever and rod arrangement. When the ball nut moves to the left from the neutral position the brake is applied, again through a lever and rod arrangement. Stops on both of the levers prevent either the brake lever or the throttle lever from going past their neutral positions.

The face cam is not connected to either of the levers; it merely applies force in one direction. To retract the brake or throttle requires the action of the springs on these pedals. There is also a linear constant-force spring that pulls the face cam to the left with a force of about 10 lbs (45 N). In the event of a power failure or intentional shutdown of the motor, this spring is enough to backdrive the ballscrew and motor, and to lightly apply the brake. There is no brake on the motor. There is little friction in the lever attached to the throttle, so the spring in the throttle is enough to return the throttle to idle once the face cam is pulled out of the way by the linear spring. Releasing a thumb or foot switch can also shut down the system.



**Figure 1: BTR Mounted in Vehicle
(with ASC also Shown Mounted in Vehicle)**



Figure 2: Close-up View of BTR Mounted in Vehicle

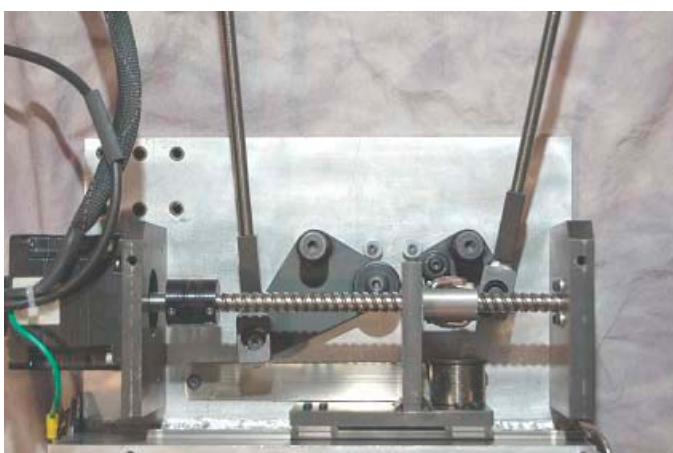


Figure 3: BTR with Cover Removed Showing the Internal Mechanism (Top Down View)

The body of the BTR sits on the floorboard of the vehicle just in front of the base of the driver's seat. This is normally behind the driver's feet, and it has a metal cover to keep the driver's clothing and feet out of the mechanism (See Figure 2).

The actuating rod for the throttle goes from the right side of the actuator to a fitting mounted to the right side of the throttle pedal. On the brake side the actuator rod goes to the left side of the brake pedal. This arrangement allows the driver to still get his foot comfortably on both the brake and throttle pedals. The driver keeps his right foot between the actuator rods, and applies the brake or throttle as he normally would. Typically, he would keep his right heel in a central location and pivot his foot as necessary.

This drivability feature is important in that test vehicles are often driven from a garage to a test location without the Brake and Throttle Robot being active. In this manual drive mode where the BTR is present in the vehicle but not active, there is a mechanical block that can be inserted such that the linear spring and the block

serve to keep the face cam at the neutral position. Since the face cam is not attached to either of the levers, it does not prevent the driver from applying either the brake or the throttle at any time.

This design arrangement makes it impossible to apply the brake and throttle at the same time. The designers felt that there would rarely be a vehicle test in which one would need to do this, and that using a single motor to actuate both the brake and throttle made for a simple and compact arrangement.

On the throttle side there is position feedback control via the rotary encoder attached to the servomotor. Before a test the system "learns" what encoder reading corresponds to the neutral cam position, and what encoder reading corresponds to the full throttle position.

Brake control is accomplished through position control using position, deceleration, or force feedback. During development the force feedback was accomplished in two ways. The simplest option was with a load cell in the brake actuating rod reading the total force directly being applied to the brake pedal through the actuating rod. This is good enough for basic vehicle maneuvers.

A second method of measuring brake force is to measure only the component of the rod force that is perpendicular to the brake pedal face. This can be done using a suitable arrangement of pivots and a button type load cell, or it can be done with a commercially available sensing unit. In either case, the vehicle deceleration will not necessarily be proportional to the force perpendicular to the brake pedal, as there are many other sources of non-linearity in the braking system.

INSTALLATION

The BTR is simple and quick to install. One places the device in the driver's footwell of the vehicle, restrains the BTR as needed and attaches the actuator rods to the pedals.

Several features can be used in combination to restrain the BTR. First the mass of the unit is sufficient to prevent the reaction torque from lifting the BTR off the floor. Second, the rear edge of the BTR is positioned against some feature at the rear of the footwell, such as a ridge in the floorboard or the rails to which the driver seat is attached (See Figure 2). This counteracts the rearward pedal reaction force. Third, a ratchet strap is threaded through tie-down rings on the BTR's rear corners to the driver seat base, further securing the BTR. Fourth, a turnbuckle type strut may be used between the dash and the BTR to hold the front end down. Finally, Velcro pads may be attached to the bottom of the BTR base to adhere to the vehicle carpet