The Proportioning Valve (UT25)

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1. Introduction

The proportioning/differentional valve is an adjustable valve connecting the rear brake master cylinder on the pedal tray to the rear brake hydraulic circuit. Its main purpose is to allow race engineers and drivers to quickly and accurately adjust the rear brake bias to optimize braking force in differing conditions.

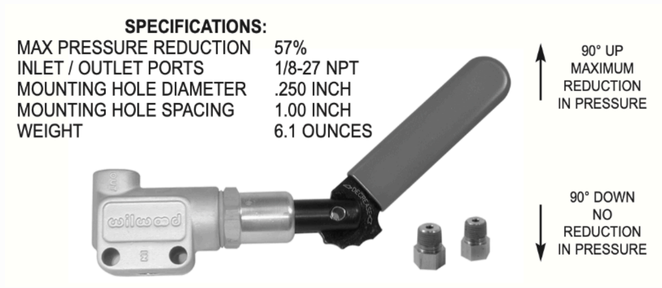

Figure 1. Specifications of UT25 prop valve (Wilwood)

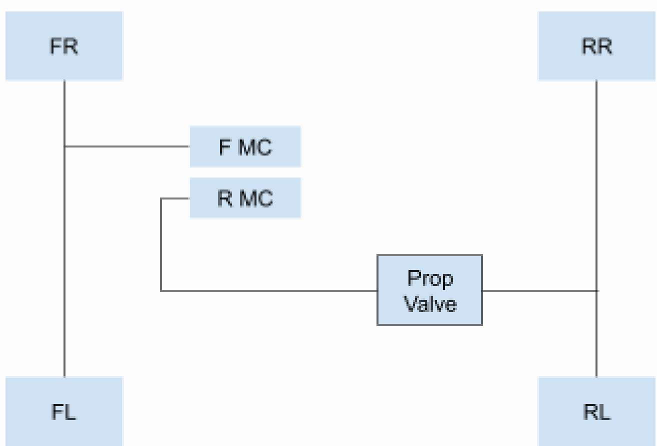

Figure 2. Connections of the prop valve. Note the valve has no effect on the front brake circuit.

2. Mechanism

Functionally, the proportioning valve begins to regulate rear brake pressure once the input hydraulic pressure exceeds a specific threshold, determined by the valve's notch setting. Above this threshold, the valve reduces the pressure transmitted to the rear brake circuit, delivering less pressure than what is output by the rear master cylinder.

This function allows adjustments to the rear brake pressure just by changing the handle position between preset notches, without requiring tuning on the pedal tray during the often hectic environment during race days.

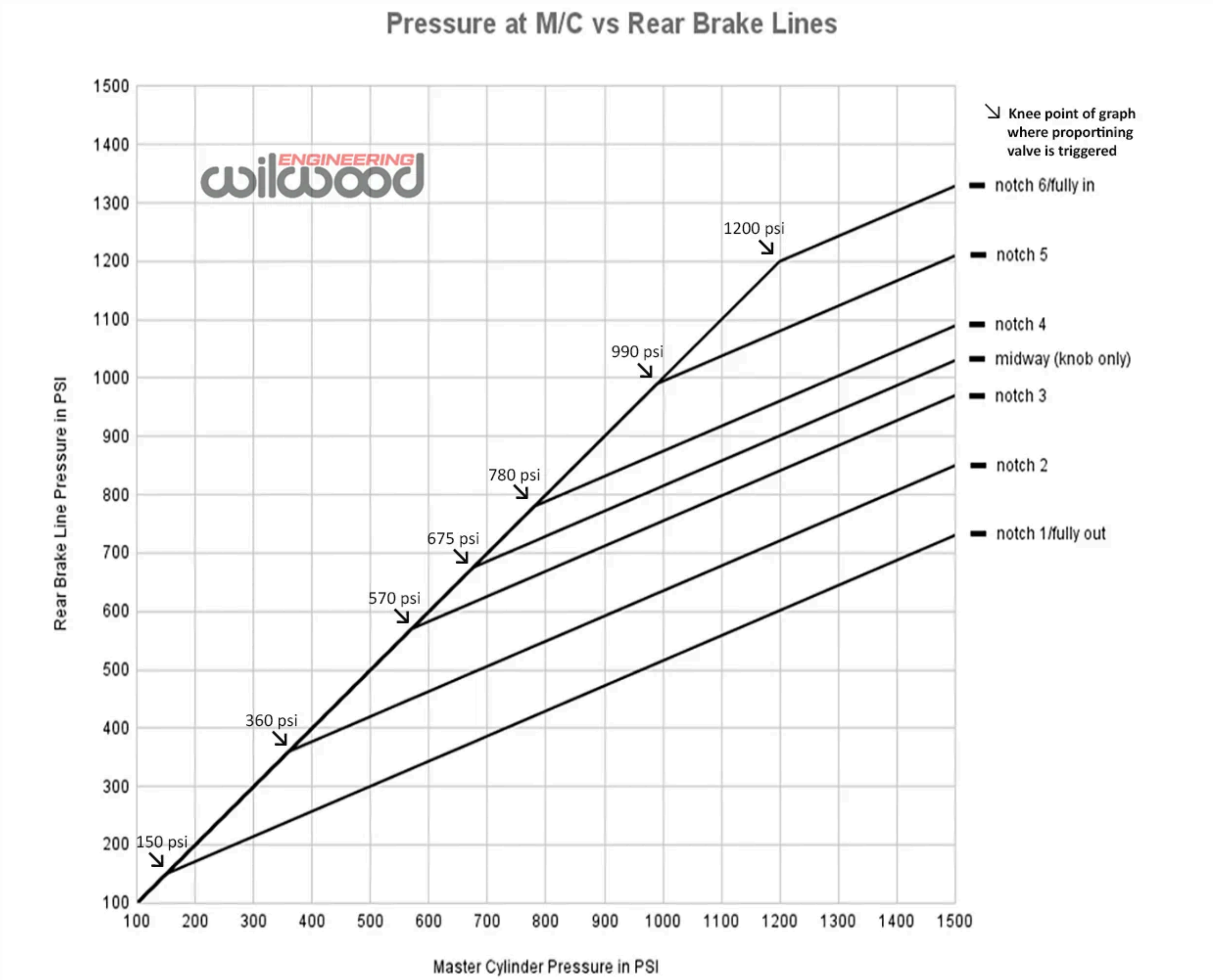

Figure 3. Knee points (thresholds) for each notch configuration of UT25 valve

Note that the bias balance bar connecting the brake pedal shaft to the MC piston rods also exists to regulate and adjust brake bias. However, the bias bar is always active regardless of pressure, and is also more difficult to quickly adjust, requiring the removal of the piston rods and nut caps.

With the prop valve, the brake bias can change with respect to pressure, allowing us to capture more braking force at lower decelerations. This concept is explored further later in this document.

3. Basic Vehicle Dynamics

Without going into excessive detail, weight transfer and brake bias will be briefly touched upon. For a more comprehensive explanation refer to the Brakes Calculation Guide (2022) by Asal Ghorbani.

A vehicle in deceleration will experience weight transfer to its front axle since its center of gravity (CoG) is a non-zero distance above the axles. This results in the front wheels having more normal force from the ground, allowing the application of more braking force without wheel lockup. Wheel lockup is suboptimal since the kinetic friction force is always less than the maximum static frictional force, as well as the loss of driver control presenting safety issues.

To find the weight transfer for a given braking force/deceleration, the height of the load vehicle's CoG, wheelbase length (L) and the associated braking force is needed.

$$\Delta W = \frac{F_{brake} h_{CoG}}{L} \tag{1}$$

The optimal braking system takes advantage of this weight transfer to achieve maximum deceleration while still being in control of the vehicle.

4. Ideal Brake Curve

The ideal brake curve is a basic model of a vehicle that visualizes the optimal front/rear braking forces for given deceleration values, while taking into account the friction coefficients of the wheels to also demonstrate the threshold braking force.

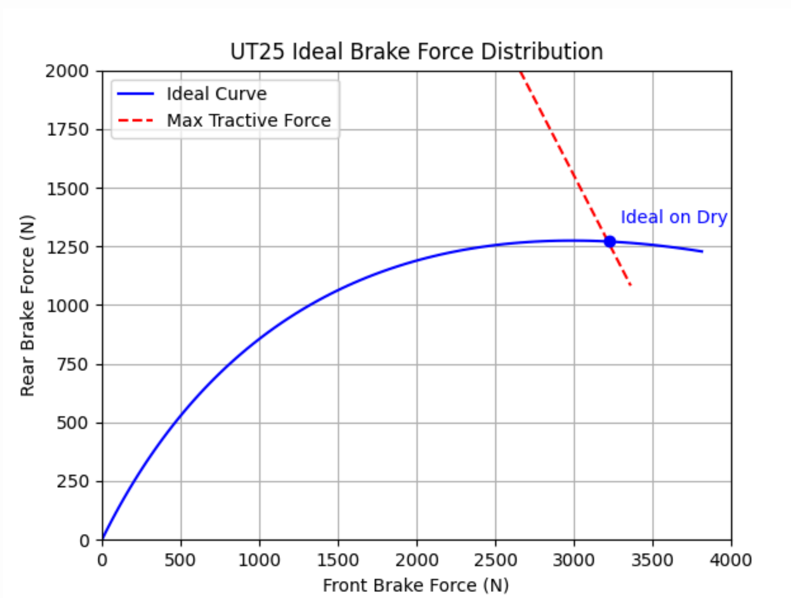

Figure 4. Ideal braking curve for UT25. Also labelled is the ideal operating point for the desired 1.61g deceleration using the appropriate tractive for line from (slicks on dry pavement) tire friction coefficients.

This curve is constructed by plotting the front/rear distribution of braking force required for a range of decelerations, taking into account the weight transfer (1) that occurs at each deceleration value. Additionally, the maximum tractive force line is constructed by calculating the maximum possible front/rear braking force supplied considering the respective deceleration/weight transfer values. Having an actual braking system as close to this theoretical idea betters control of the vehicle and reduces wear by evenly distributing the brake force.

With solely a bias bar and no proportioning valve, the actual braking force curve is linear, as the bias bar dictates a static bias regardless of the pressure being applied by the pedal.

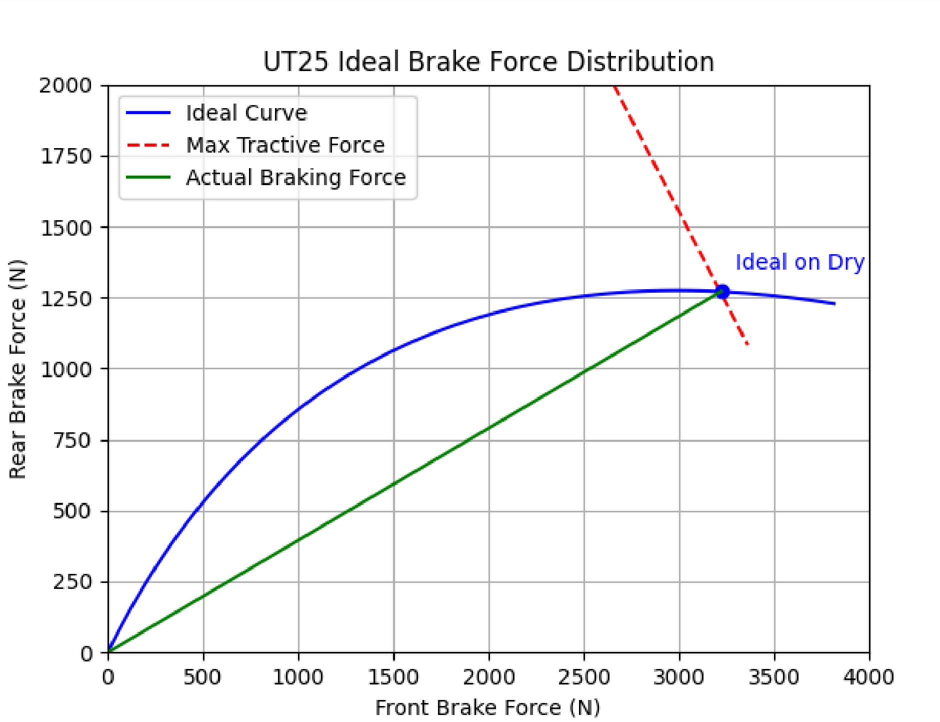

Figure 4. With the actual (green) braking force, a difference in braking force up to the ideal point can be observed.

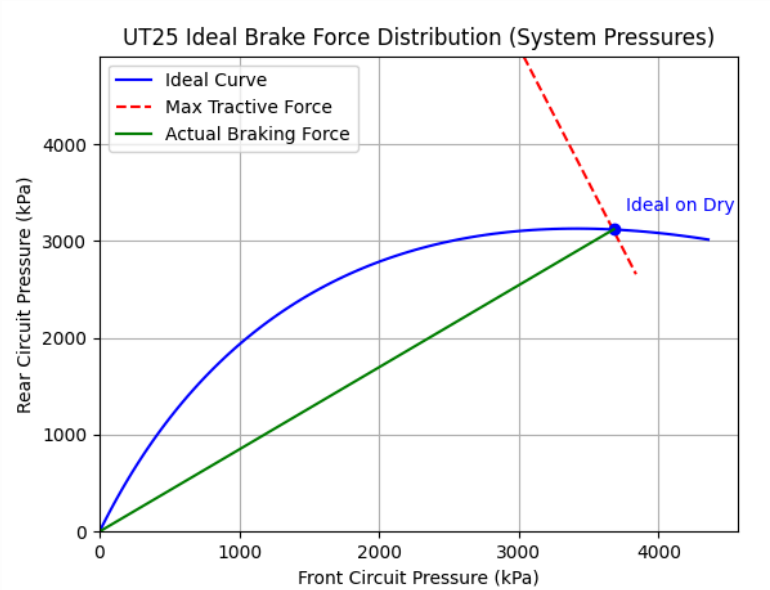

Figure 4.1. Same figure, in front/rear circuit pressures rather than braking force.

With this in mind, an area of inefficiency can be seen, where more rear braking force can actually be applied without losing control and leading to a more evenly braking vehicle, helping with possible steering balance issues.

With a proportioning valve, the actual braking force curve can feature a knee point similar to in Figure 3 at the rear braking force associated with the chosen MC pressure threshold.

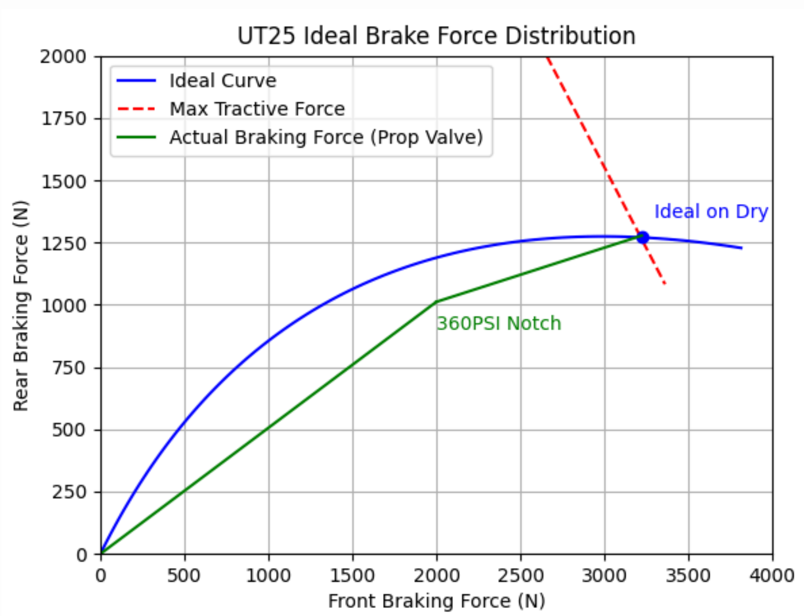

Figure 5. With the valve at notch 2 (360PSI), the actual braking force exhibits a knee point at around 1350N of rear braking force.

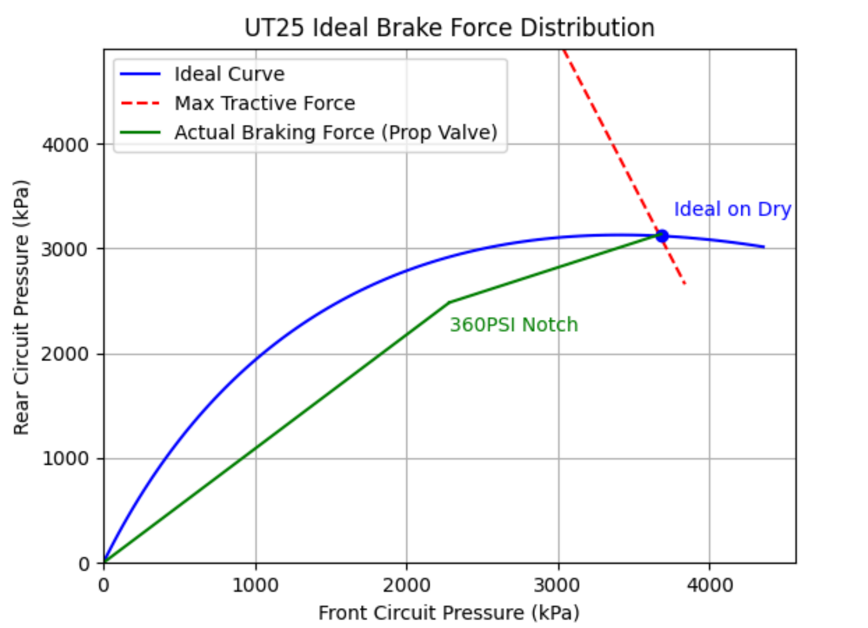

Figure 5.1 Same figure, in front/rear circuit pressures rather than braking force.

An actual braking curve closer to the ideal curve develops a car that is more front/rear balanced when braking, as well as more even brake wear and less premature rear brake engagement in turning.

It is also important to note that the circuit pressures required for braking are generated by front/rear MC pushrods. These pushrods, attached to a slightly front heavy bias bar, is able to generate the ideal pressure with the same size MCs, relying on the lower piston count of the rear brake callipers to significantly brake front heavy.

Additionally, considering the importance of the Endurance dynamic event, the regenerative braking force (a rear axle braking torque coming from running the main motor in reverse) must also be taken into account for this configuration.

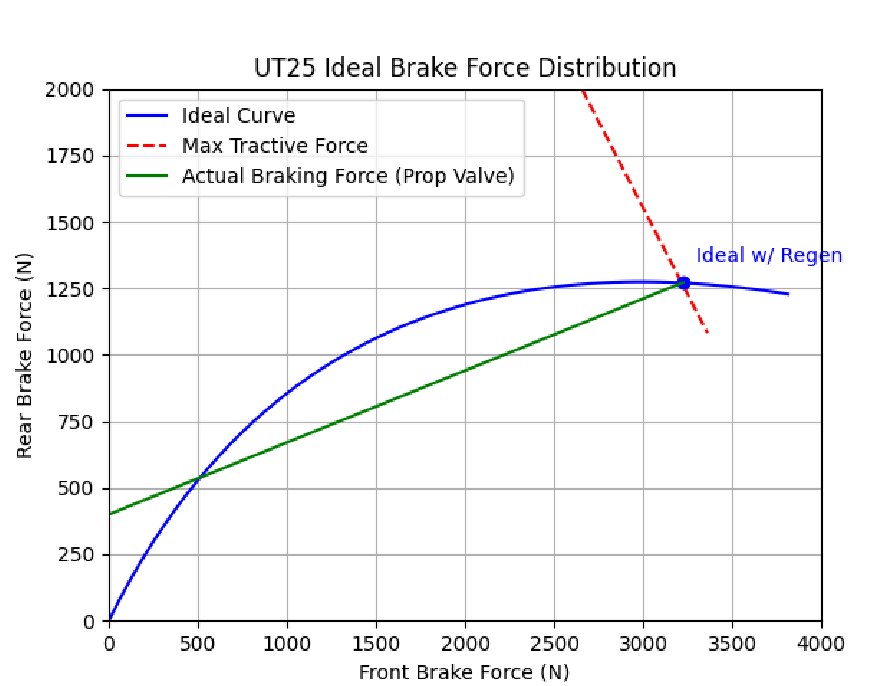

Figure 6. With regen braking in Endurance, the prop valve is set at notch 6, effectively disabling it.

It is important to note that with regen activated, the efficiency of this system decreases, as the prop valve is better off disabled. With UT25's underpowered rear braking circuit, the benefits that come with the proportioning valve (the knee point in Figure 5) are lost in Endurance, demonstrating an area for improvement in the future.

5. Testing Data and Plans

The most recent testing data we have on hand is with a broken proportioning valve.

For the UT25 vehicle, the proportioning valve configurations are listed below for reference.

AutoX: Recommended notch 3 (drivers have slightly differing preferences of 2-4)
Endurance: Notch 6 (effectively no rear choke) + Regenerative Braking
Wet/low friction: Notch 6 (effectively no rear choke to oppose understeering)

Moving forward, basic testing to verify the performance of the valve should be done. During testing months, time is not plentiful, and tests of the valve should be done quickly so that adjustments to the theoretical model and physical configuration may be made if needed.

A simple test to maximize braking force without locking wheels could be a straightaway of two sections, accelerating and braking, similar to the Brake Test at Michigan. The driver operated vehicle should accelerate over the first distance, applying the brakes at marked pylons and coming to a complete stop.

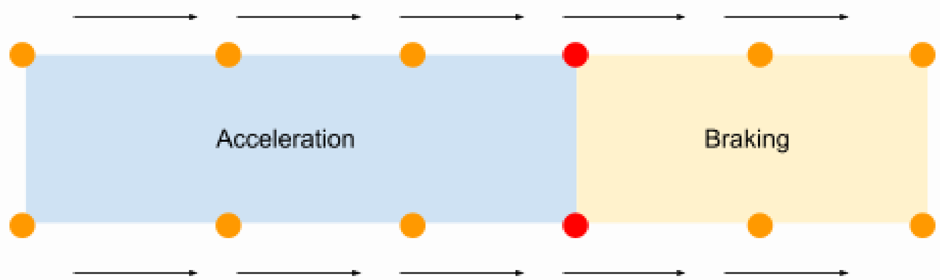

Figure 7. Basic diagram of testing straightaway for brakes. Red and orange pylons mark braking start and testing area, respectively.

Each run should have a different prop valve configuration (with a fixed balance bar) to verify underpowered configurations and ones that lock the rear wheels. Data on the vehicle speed right before braking, stopping distance, wheel locking, as well as qualitative data on aspects such as approximate vehicle yaw angle if any spin occurs.

This data should help validate theoretical models for AutoX or otherwise improve our calculations. Additionally, if similar tests may be done with regenerative braking activated, that would also be beneficial.

6. Other Considerations

- *Flexibility* offered by the valve is also useful to adjust for driver preference

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