# Interpreting WheelWatcher™ Graphical Results

What follows is a general discussion on the interpretation of various graphs provided by WheelWatcher™. The graphs presented were taken from actual data from a prototypical installation. The prototype installation lacked a great deal of resolution, but it is quite sufficient to observe various aspects of bottle formation.

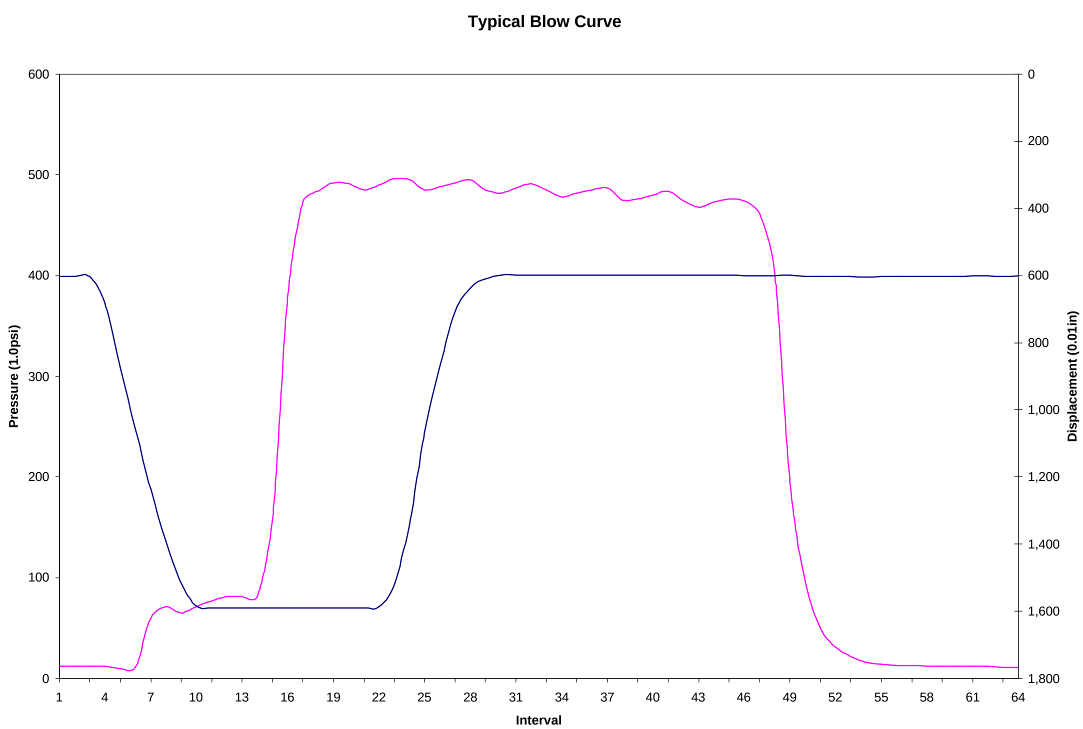
These graphs are not intended to represent the WheelWatcher™ operator interface. These data are presented offline and in the context of analyzing the nature of stretch blow molding bottle formation.

Combined plots of the time scale, first order derivative and second order derivative are presented. Later, the two parameters are investigated in more detail with only one parameter per plot.

Inasmuch as the bi-orientation of the material in plastic bottles is critical to their strength, the importance of velocity and acceleration of both the stretch rod and the blow pressure can not be understated. A great deal can be learned by observing both the slope and amplitude of these plots. Equally important in creating profiles used to detect bad bottles are the differences in absolute magnitude of the rapid excursions used to orient the bottle material.

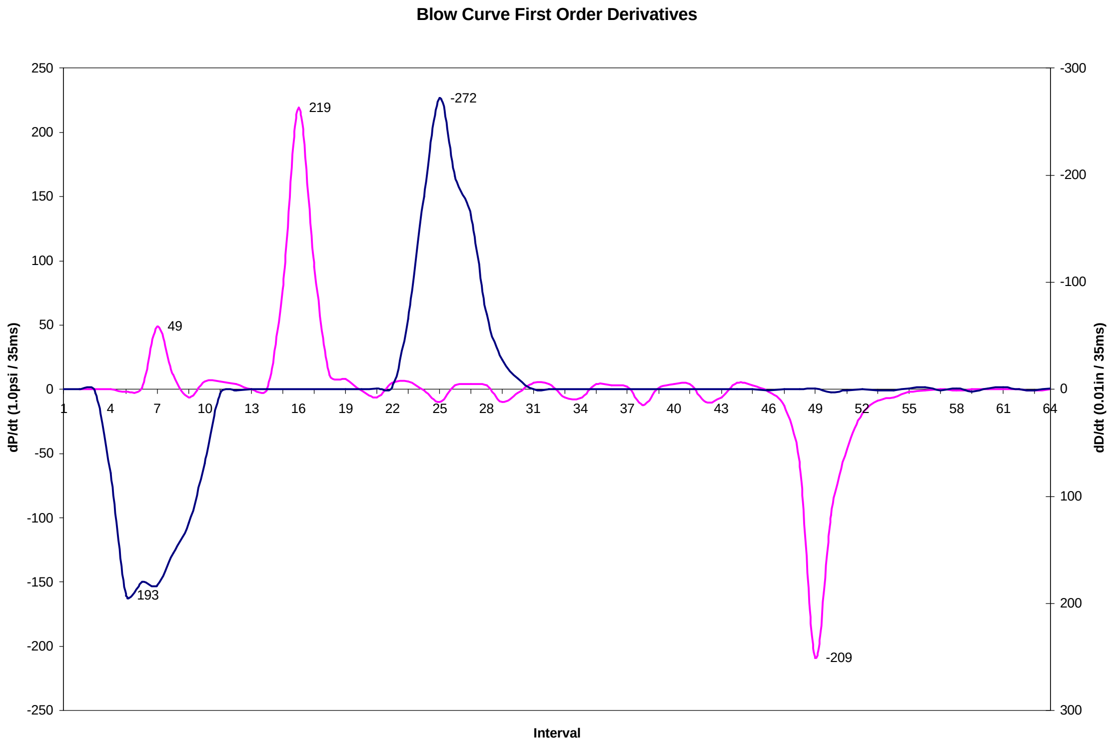
While this document presents various graphs for a “good” bottle, the reader may be interested in similar views of data taken from “bad” bottles. For more information, please contact Keeva.

When one sees the typical WW blow curve, as seen below, it is immediately obvious what is going on. Indeed, as we have seen, there are many production, maintenance and quality control related problems that are currently detected by WW. While the plot below doesn't indicate any real problems, the following discussion shows how advanced algorithms can reveal more about the process.



## Combined Displacement and Pressure First Order Derivatives

If we take the first order derivative of the blow curve data, we get the plot shown below.

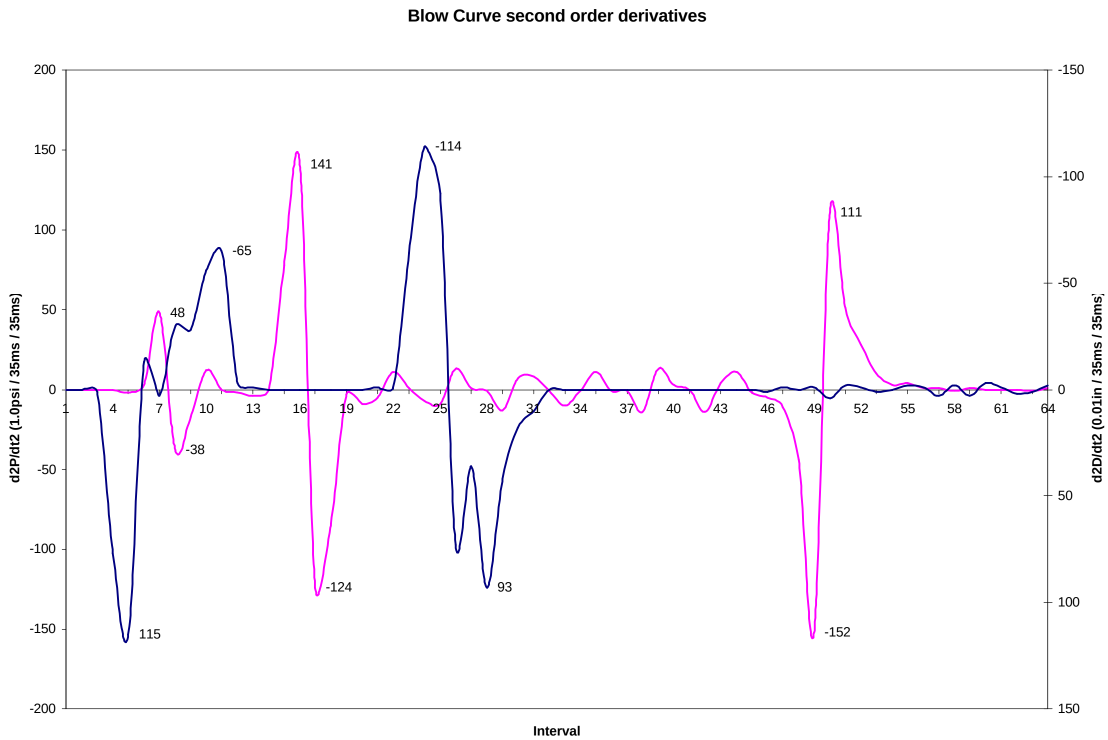



This graph is presented here to show the relationship between the two parameters. In later sections, the discussion will examine one parameter per graph to avoid clutter and confusion.

It is helpful to keep this plot available when considering each parameter separately. By comparing each parameter to the other, greater insight can be gained. The two plots are synchronized in time to facilitate this comparison.

## Combined Displacement and Pressure First Order Derivatives

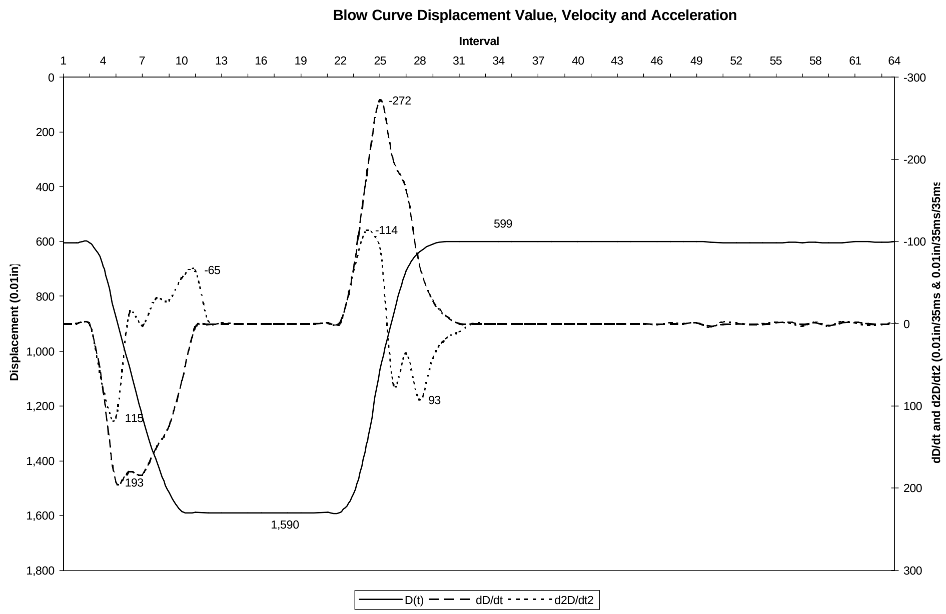
One can also tell a great deal about the process from the second order derivative shown below in the combined view. Again, we'll look more at the second order derivative interpretation later with one parameter per graph.




Keep in mind that the displacement graphs are all presented with an inverted axis. Because it is easier to visualize the stretch rod going down during extension, all displacement scales are shown in reverse order.

## Combined Displacement D(t), dD/dt and d2D/dt2 Curves

In this view all three displacement curves are shown together. This is especially helpful in visualizing the relationships between curves.

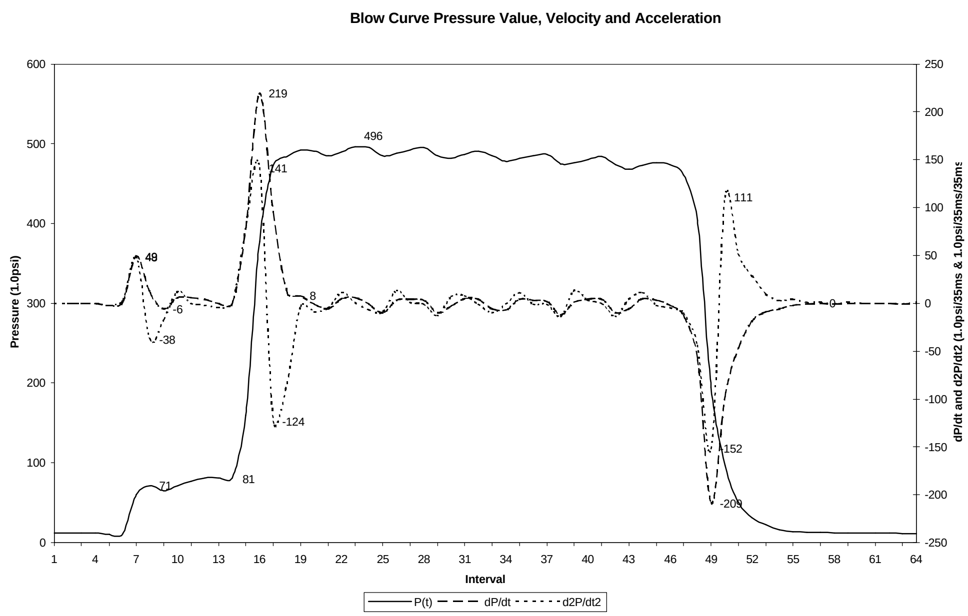



This graph is presented here to show the relationship between the two parameters. In later sections, the discussion will examine one parameter per graph to avoid clutter and confusion.

It is helpful to keep this plot available when considering each parameter separately. By comparing each parameter to the other, greater insight can be gained. The two plots are synchronized in time to facilitate this comparison.

## Combined Pressure P(t), dP/dt and d2P/dt2 Curves

In this view all three pressure curves are shown together.  This is especially helpful in visualizing the relationships between curves.

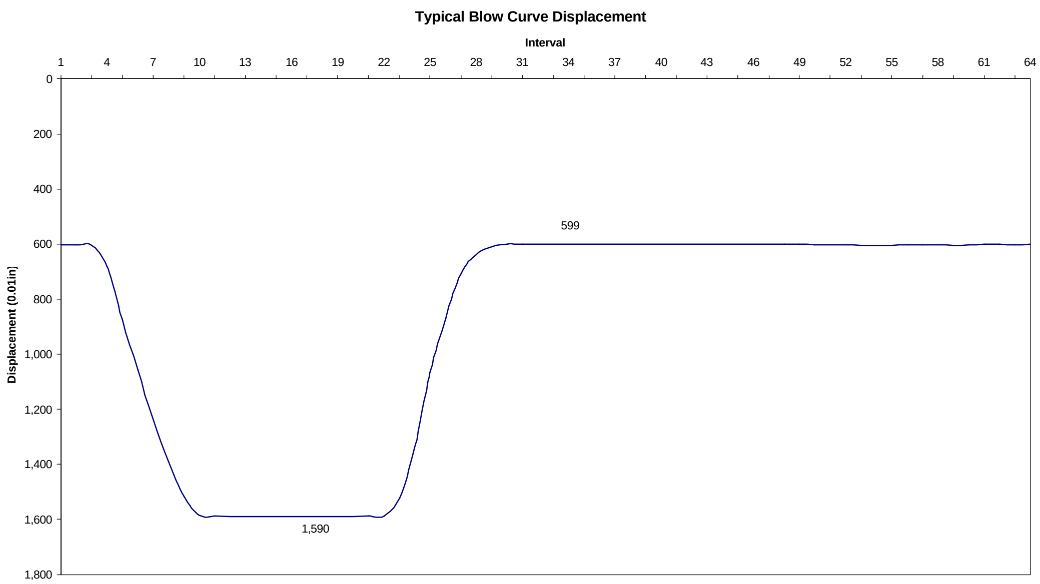


## Displacement as a Function of Time

The graph below repeats the displacement graph as a function of time as shown on the first, combined plot. In this view, the pressure curve has been removed to improve the clarity.

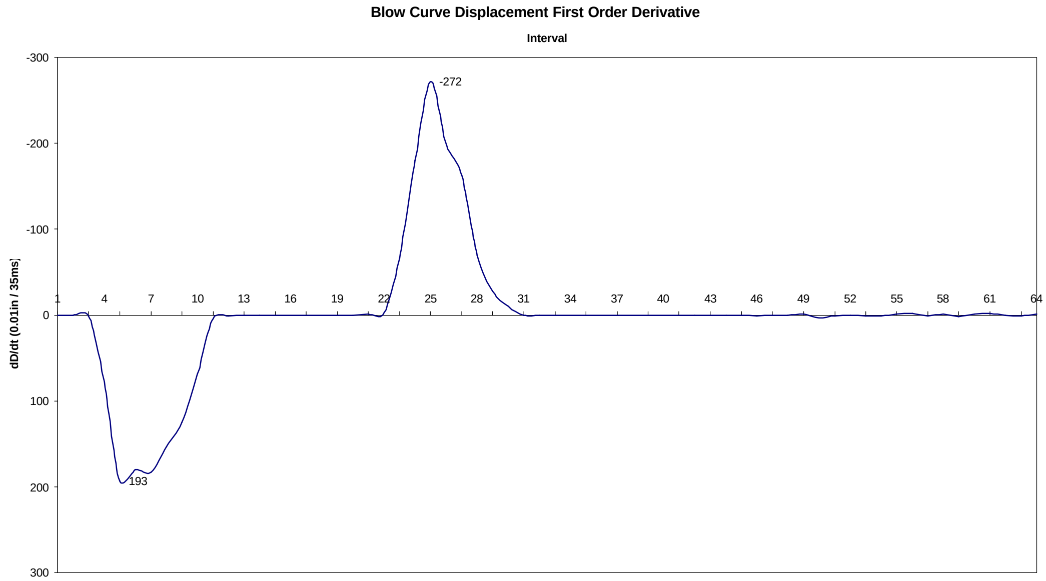
The stretch rod extends to push or stretch the preform to the bottom of the mold. Once there, the stretch rod holds the preform down near the mold bottom to allow the high-pressure air to form the bottle. Once the high pressure has been applied, the bottle has cooled to the point where it is rigid. The stretch rod then retracts and the bottle continues to cool since the high pressure holds the bottle against the water-chilled mold. With the stretch rod out of the way, the high-pressure air is exhausted and the bottle is removed from the mold.

One can see the slight ripple in the downstroke, but it is not really obvious. Observe the slowness of the retraction near the top of the stroke. This is caused by an adjustment problem on the retract cushion. The desired response is for the upstroke to proceed smartly to the retracted position rather than lag as it does here. By adjusting the exhaust port of the air cylinder, the rod will not creep so.



## Displacement First Order Derivative or Velocity

In the first order derivative plot below, notice how obvious the difference is between stretch rod down-stroke and upstroke.




The first order derivative plot indicates the velocity. This plot, like all displacement plots, has the ordinate (y-axis) or displacement plotted in reverse scale. When the slope of the line is positive or downward the velocity is increasing. Conversely, if the slope is upward the velocity is decreasing. If the slope of the line changes several times as in the downstroke shown above, this indicates a jerking action during extension. The number of slope reversals is an indication of the smoothness of the motion. This could be vibration in the cylinder bearing or simply the stretch rod overcoming the resistance of the preform or parison as it is stretched.

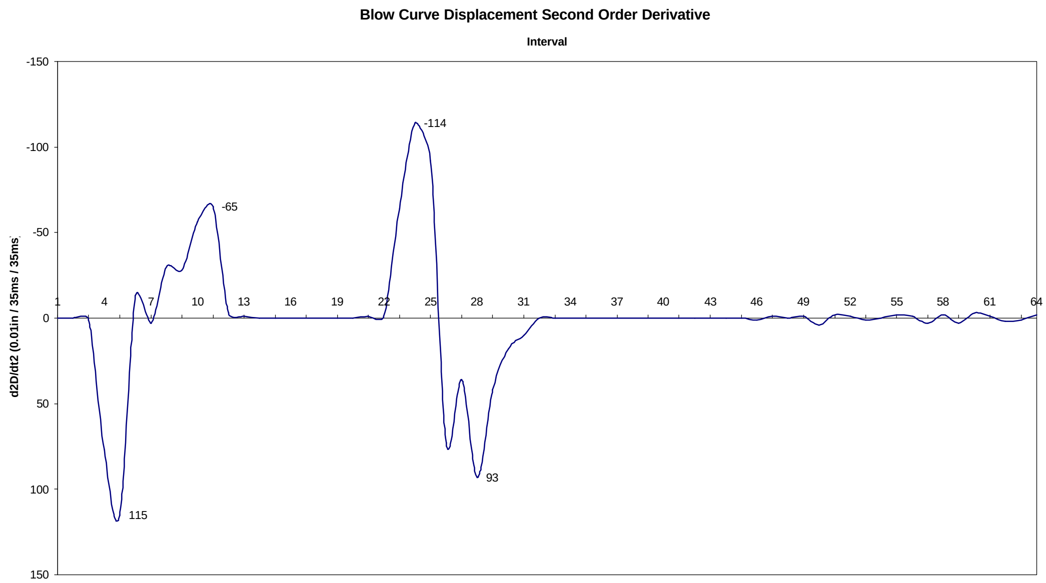
The magnitude of the dD/dt peak is an indicator of the speed of the stroke. In this case, the absolute value of the upstroke or retraction (-23) is greater/faster than the down-stroke or extension (14). This makes sense since it is easier to retract the stretch rod without resistance than it is to stretch the bottle during extension.

Ideally, the excursions on this plot should look like triangles. Obviously, the extension should be investigated. The ripple seen at the end of retraction is how the aforementioned cushion shows up on the velocity plot.

In most cases the effects are easier to see in this plot than they are in the plot as a function of time only. All of the effects discussed here are easier to see.

## Displacement Second Order Derivative or Acceleration

If the first order plot should ideally look like triangles, the second order plot should look like spikes in the direction of the slope of the triangle in the first order derivative. You can imagine these spikes laid over the plot below if you look only at the largest excursions.

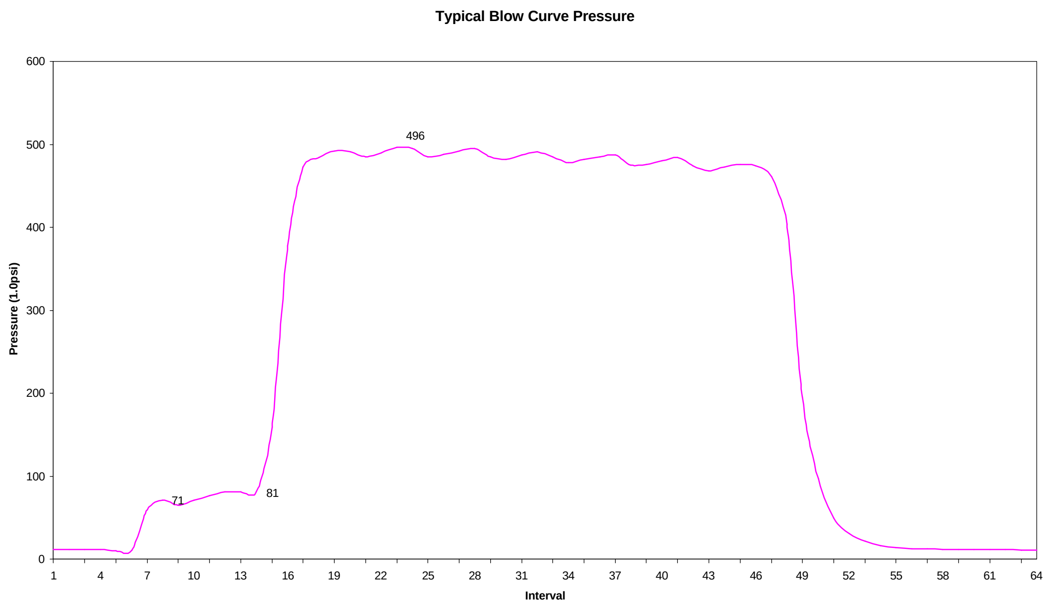



The magnitude of the excursions indicate the acceleration or how fast the velocity of the rod is changing. Once again, you want the plot to be uniform in the desired direction. The jerking of the rod can be seen even easier in this view. The number of transitions between the adjacent minimum and maximum are the number of times the rod accelerated or decelerated over that interval. During the extension, the jerking occurred four (4) times that WW was able to record. During retraction there were really no such jerks. It is very obvious that between extension and retraction there were no surprises as the acceleration was zero (0). This would not be the case in the instance where the center rod was lifted up by the high-pressure blow. WW has trapped this phenomenon and the results are dramatic in this type view.

## Pressure as a Function of Time

Much of the above explanation applicable to displacement applies to the blow pressure. In the graphs below, the blow pressure is shown by itself and as a function of time.

The bottle formation begins as the stretch rod starts down. With the stretch rod in motion, the low-pressure air keeps the preform from collapsing on the stretch rod as it stretches the material down inside the mold. When the stretch rod reaches the base of the mold, the blow pressure is switched to high pressure. The high-pressure acts to force the now stretched preform into the inside of the mold. The high pressure is held for an interval to allow the plastic material to cool as it is now in contact with the mold. The mold is chilled with process water to speed the cooling or curing process. Finally, the air is exhausted in preparation to extract the now completely formed bottle from the mold.

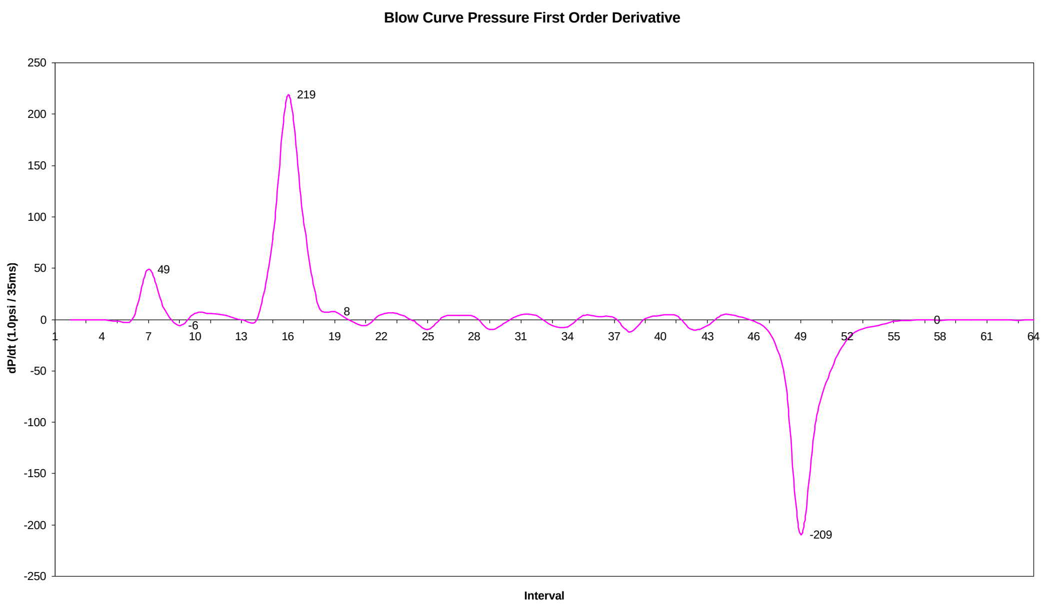


## Pressure First Order Derivative or Velocity

Considering the pressure velocity plot below, it is clear the low-pressure velocity is relatively slow compared to the high-pressure charge. It is also easy to see the exhaust or depressurization phase velocity is less than the pressurization phase. This makes sense, as there is a great deal of pressure behind the pressurization action, while depressurization simply exhausts to the ambient atmosphere.

One would think the low-pressure velocity is not so important as the high-pressure velocity since the low-pressure charge serves to keep the preform off the stretch rod as it extends. However, the high-pressure charge is important because it is used (with the stretching action) to align the polymer chains and give the bottle its rigid properties.

By observing the plot, one can see that if it became important to gain cycle time during the exhaust phase, a negative pressure or vacuum could be applied to the exhaust port.



## Pressure Second Order Derivative or Acceleration

Because of the symmetry of the first order plot, the second order plot is likewise symmetrical. This plot simply reinforces the earlier observations about the pressure activity. If there were a problem or an anomaly, however, it would show up quite dramatically in the view.

## Blow curve analysis ratios, indices and values

WheelWatcher extracts several key ratios, indices and values from the data points sampled over a bottle formation cycle. Many times these results are used to characterize the results of the blow mold process and are used as discrimination factors in decided to reject a bottle. This section presents these results and their interpretations.

Advanced WheelWatcher installations use more complicated regression, curve fitting and filters to provide other data valuable in research, development and quality control efforts.

The reader will find it helpful to use a copy of the combined charts when considering these blow mold metrics.

### Minimum Low Blow Pressure

Minimum pressure recorded over the low blow interval.

This value is used to determine if sufficient blow air is available to keep the parison from coming in contact with the stretch rod during longitudinal orientation. As the stretch rod moves down and elongates the parison would collapse on the stretch rod were it not for a cushion of air to billow or buffer the parison from the stretch rod.

If this value is less than the Minimum Low Blow Pressure Preset then
blow air is not available
an open point exists is the blow air circuit
a valve problem exists
the preform has blown out

### Maximum Low Blow Pressure

Maximum pressure recorded over the low blow interval

If the Maximum Low Blow Pressure exceeds the Maximum Low Blow Pressure Preset then
a three way valve has failed
the low blow pressure regulator is set too high
a neighbor's three way valve has failed
an obstruction exists in the blow air circuit

### Minimum High Blow Pressure

Minimum pressure recorded over the high blow interval

This value is used to determine if sufficient blow air pressure and volume is available to cause acceptable radial orientation of the bottle. After the stretch rod has reached it maximum extension the high blow air is applied to the preform. The high blow air forces the now elongated bottle into the inside of the mold cavity. The volume and pressure must be sufficient to force the material into intricate mold designs. When the preform material comes in contact with the mold heat is lost and the material changes properties very quickly. If there is not enough radial velocity, the material will chill sufficiently to not allow proper bottle formation.

If this value is less than the Minimum High Blow Pressure Preset then
blow air is not available
an open point exists is the blow air circuit
a valve problem exists
the preform has blown out

### Maximum High Blow Pressure

Maximum pressure recorded over the high blow interval

If the Maximum High Blow Pressure exceeds the Maximum High Blow Pressure Preset then
the high blow pressure regulator is set too high
an obstruction exists in the blow air circuit

### Pressure Reference

Minimum pressure recorded over the entire interval

If the Pressure Reference exceeds the Pressure Reference Preset then
the transducer is not calibrated
a valve failure is constantly applying blow air to the air circuit
blow air is trapped in the air circuit
noise is being induced in the transducer wiring

### High Pressure Bypass

MXLBP – MNLBP

Difference between Maximum and Minimum Low Blow Pressure

In the event of a three-way valve failure this value exceeds the High Pressure Bypass Preset

### Shut-In Pressure Drop

MXHBP – MNHBP

Difference between Maximum and Minimum High Blow Pressure

This values gives and indication of the air pressure leakage that occurs while the bottle is being cooled. With high blow air applied to the bottle a leak may occur at the o-ring seal or another place in the air circuit.

### Minimum Stretch Displacement or Displacement Reference

Minimum displacement recorded over the non-longitudinal orientation interval

If the Displacement Reference exceeds the Displacement Reference Preset then
the transducer is not calibrated
a mechanical problem exists
noise is being induced in the transducer wiring

### Maximum Stretch Displacement

Maximum displacement recorded over the longitudinal orientation interval

If the Maximum Stretch Displacement exceeds the Maximum Stretch Displacement Maximum Preset then
the transducer is not calibrated
a mechanical problem exists
noise is being induced in the transducer wiring

If the Maximum Stretch Displacement is less than the Maximum Stretch Displacement Minimum Preset then
the transducer is not calibrated
a mechanical problem exists
noise is being induced in the transducer wiring

### Extension Velocity

Maximum extension velocity detected over the extension interval.

This value gives a direct indication of the longitudinal orientation process.

**Retraction Velocity**

Maximum retraction velocity detected over the retraction interval.

**Low Blow Velocity**

Maximum blow velocity detected over the low blow interval.

This value gives a direct indication of the ability of the air system to keep the preform from collapsing on the stretch rod during longitudinal orientation.

**High Blow Velocity**

Maximum blow velocity detected over the high blow interval.

This value gives a direct indication of the radial orientation process.

**Blow Pressure Ratio**

High Blow Velocity divided by Low Blow Velocity.

This ratio is used to ensure the preform is not overly stretched radially during stretch rod extension.  Too low a number indicates that too much radial orientation may be occurring during stretch rod extension rather than after longitudinal orientation has finished.

**Stretch Bilateral Resistance Ratio**

Peak Extension Velocity divided by Peak Retraction Velocity

This ratio is an indication of the health of the stretch rod extension.  The mechanical system can only move so fast.  The retraction portion of the cycle should be the fastest. By normalizing the extension velocity by the retraction velocity the relative success or health of extension is clearly measured.  Additionally, a properly heated preform offers less resistance to the stretch rod extension.  Lower numbers indicate a labored extension and a direct indication of problematic extension.

**Stretch Spread**

Absolute value of the Retraction Velocity less the Extension Velocity

This value is a direct indication of the overall health of the stretch rod operation.  Leaking seals or otherwise defective air cylinders are apparent from this value.

**Blow Spread**

Absolute value of the High Blow Velocity less the Exhaust Velocity

If this spread is too great there is too much disparity between the inlet and outlet of the air circuit.

**Exhaust Ratio**

Exhaust Velocity divided by High Blow Velocity.

Normalized by the high blow velocity, this measure of exhaust performance provides a relative indicator of the exhaust process.

**Exhaust Velocity**

Maximum blow velocity detected over the exhaust interval.

This value is a direct indication of the ability of the station to get rid of blow air prior to bottle extraction.

### Retraction Settle Index

Elapsed time from maximum Extension Velocity to first zero velocity or Displacement Reference Velocity.

Where the Settle Roughness Index indicates the smoothness, it is possible to constrict the stretch rod exhaust port so much that the stretch rod does not retract quickly enough. By using this index with the Settle Roughness Index, maintenance personnel can be sure the port is set properly.

### Settle Roughness Index

Number of acceleration sign reversals between the onset on stretch rod retraction and Stretch Acceleration Reference

This index provides a direct indication of the bounce the stretch rod sees as it settles in the retraction position. This index is used mainly to ensure the stretch rod cylinder exhaust port is properly adjusted.

### Extension Roughness Index

Number of acceleration sign reversals between the onset on stretch rod extension and maximum Stretch Displacement.

This value indicates the amount of jerk or vibration during stretch rod extension. As the stretch rod cylinder overcomes the resistance of the preform there is some surging or plugging as the air pressure builds in the cylinder and overcomes the static coefficient of friction in the cylinder, bushings and even in the preform.

### Retraction Roughness Index

Number of acceleration sign reversals between the onset on stretch rod retraction and Stretch Acceleration Reference

The retraction movement should be smooth. Normally, there are no significant friction forces to overcome. However, in the event of mechanical misalignment or binding, this index can be used as a predictive maintenance indicator.

### Extension Attack Ratio

Peak Extension Acceleration divided by Peak Extension Deceleration

This ratio is an indication of the aggressiveness of stretch rod extension. As the air cylinder moves, the volume increases exponentially while the extension increases linearly. The stretch rod should speed up faster than it slows down. Also, the nature of the preform at it initial state is very different than when elongated. This ratio is another measure of the health of the extension function.

### Retraction Attack Ratio

Peak Retraction Acceleration divided by Peak Retraction Deceleration.

This ratio is an indication of the aggressiveness of stretch rod retraction. As the air cylinder moves, the volume decrease exponentially while the retraction proceeds linearly. The air must escape through an adjustable orifice. The stretch rod should speed up faster than it slows down. This ratio is another measure of the health of the retraction function.

### Low Blow Attack Ratio

Peak Low Blow Acceleration divided by Peak Low Blow Deceleration.

This ratio allows quality tracking for a parameter that should remain near unity. Any asymmetry in the blow acceleration over this interval indicates a serious blow air problem.

### High Blow Attack Ratio

Peak High Blow Acceleration divided by Peak High Blow Deceleration

This ratio allows quality tracking for a parameter that should remain near unity. Any asymmetry in the blow acceleration over this interval indicates a serious blow air problem.

### Exhaust Attack Ratio

Peak Exhaust Acceleration divided by Peak Exhaust Deceleration

This ratio allows quality tracking for a parameter that should remain near unity. Any asymmetry in the blow acceleration over this interval indicates a serious blow air problem.

### Bi-orientation Index

Normalized arctangent of normalized and shifted High Blow Velocity divided by normalized and shifted Extension Velocity.

$$BOI = \arctan\left[\frac{(HBV / NHBV) - 1}{(EV / NEV) - 1}\right]$$

where NHBV is the Nominal High Blow Velocity value and NEV is the Nominal Extension Velocity value for the specific product being blown.

-or-

Presented as a compound value of the Extension Velocity “by” the High Blow Velocity; for example, 193 by 219 or 193X219. The Bi-orientation Index highlights the quickness with which bi-orientation. The BOAI together with the BOI are the two most general indicators of the bottle quality.

### Bi-orientation Attack Index

Normalized arctangent of normalized and shifted High Blow Acceleration divided by normalized and shifted Extension Acceleration.

$$BOAI = \arctan\left[\frac{(HBA / NHBA) - 1}{(EA / NEA) - 1}\right]$$

where NHBA is the Nominal High Blow Acceleration value and NEA is the Nominal Extension Acceleration value for the specific product being blown.

-or-

Presented as a compound value of the Extension Acceleration “by” the High Blow Acceleration; for example, 115 by 141 or 115X141. The Bi-orientation Index highlights the quickness with which bi-orientation. The BOAI together with the BOI are the two most general indicators of the bottle quality.