



Multi-functional Static Condition Caster Test Machine

Caster Concepts, Inc.

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Introduction:

This paper details the functionality and specifications of the multi-functional static condition caster tester developed by Caster Concepts Inc.(CCI) This test machine was built in order to verify and quantify the static characteristics of CCI's current and future product line. Specifically, the static tester has the capabilities of continuously measuring the stiffness profile of spring loaded and other shock absorption casters along their entire travel length. It can also be used to determine tread bond strength and quality of elastomer treaded wheels. Additionally, the static tester can continuously measure the resulting footprint of a wheel with respect to the load applied thus capturing the change in footprint area as the load applied to the wheel is varied.

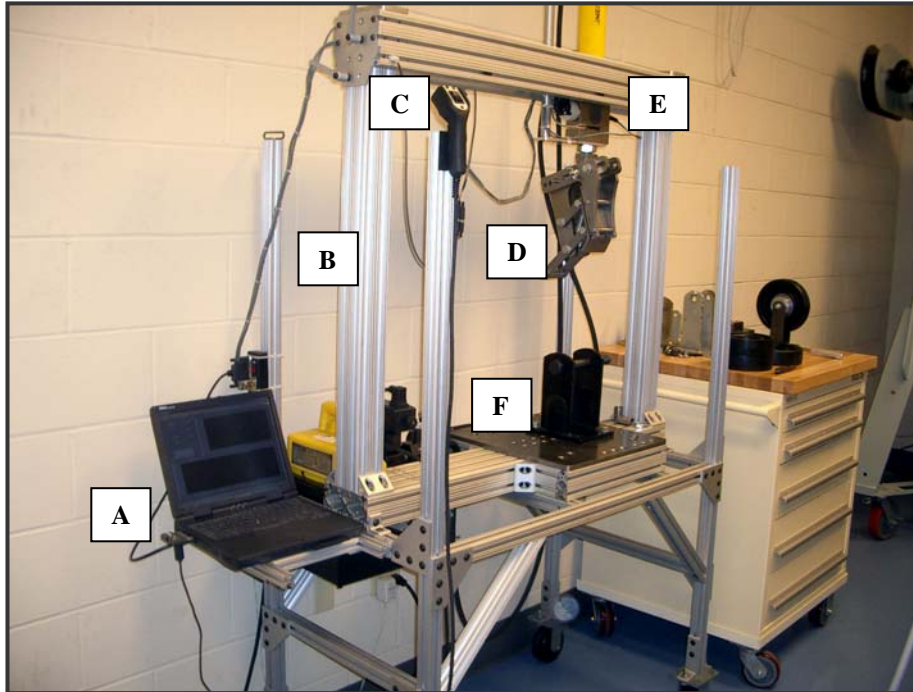
The goal of this paper is to explain the functionality of this machine and provide an understanding of the data and benefits that can be derived from its operation. This paper will describe the components that make up the test machine, outline its operation and illustrate some sample data.

General Capabilities:

In designing the spring loaded caster stiffness testing machine, our aim was to create a low cost multi-functional machine capable of generating useful data for a wide range of products. In order to reduce the cost and maintain flexibility, much of the machine is un-automated. Since operation and testing time of each specimen is relatively short, an operator is required to be present at all times. The operator duties in running the test machine include loading and unloading specimens, initiating of the data acquisition software and controlling the force actuation mechanism. Actual test procedures will be discussed in the latter part of this report.

The machine is capable of testing casters as small as a 30 series caster to as large as a 90 series caster. The mounting surface of the test machine have pre-machined and tapped holes that match standard top plates for casters from the 30 series to the 90 series. For casters with custom top plate mounting patterns, toe clamps and flexible fixturing tools are used to secure the caster to the machine base.

The machine is capable of generating and measuring 20,000 pounds of force though its hydraulic cylinder and S beam load cell. The cylinder has 10 inches of travel measured through a linear encoder. Its plunging height can be further adjusted to accommodate various caster sizes with the addition of 6" extension rods.



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|-----------|-----------------------------|
| A. | Laptop Based Data Recording |
| B. | Aluminum Frame |
| C. | Control Dongle |
| D. | End Effector |
| E. | Sensor Package |
| F. | Sample Test Base |

Actuation System:

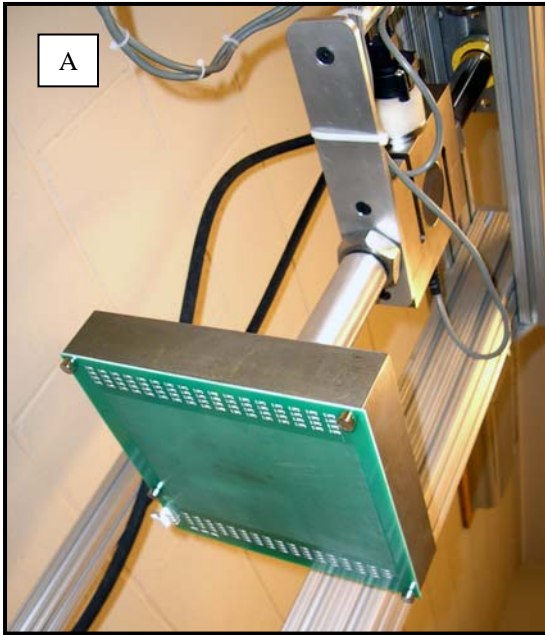
The static tester has only one powered axis of movement. The vertical movement of the plunging arm is powered by an Enerpac hydraulic piston, model number RR-1010. The piston is double acting and has a maximum pressure capacity of 10,000 psi. The maximum force this piston can exert is about 20,000 pounds. And again, as mention before, the stroke length is 10 inches.

The hydraulic pressure is supplied to the piston via an Enerpac electrically powered submerged pump, model number PER1401B. The pump has a hand held toggle control mechanism that simply turns the pump on or off. Flow control capabilities were added by placing an Enerpac V-66F flow control device on both hydraulic lines leading to the piston.

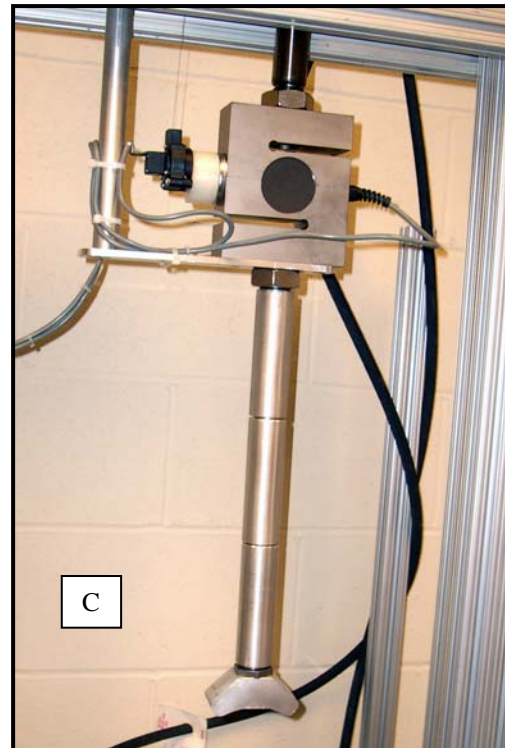
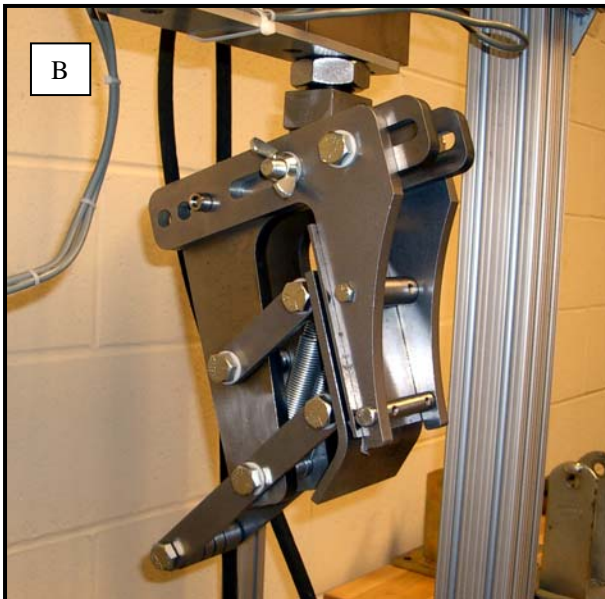
End Effectors for Multi-functionality:

In order to accommodate the various tests that this single machine needs to perform, various end effectors were design to be attached to the end of the load cell. The most simple is the solid push rod end effector used in the stiffness test to push down on the arms of a spring loaded casters. For bond tests, a four bar linkage jaw has been designed to grab and pull on the treads of wheels. As the bond test end effector pulls up on the tread tongue, the jaws are designed to close tighter and grip firmer. This design works especially well for high elongation elastomers which tends to neck down with increasing elongation. This guarantees that the tongue will not slip off during the test. The footprint

tester is composed on a steel plate under which, a specially designed circuit board is mounted. This circuit board has 120 parallel conductive lines, spaced 0.050" apart, running the length of the board. Each line is connected to the adjacent lines through a 100 Ohm resistor. A copper wire is placed onto the circumferences of the wheel to be tested. As the wheel makes contact and flattens out, the copper wire successively shorts the parallel lines thereby reducing the overall resistance of the circuitry. The change in resistance is measured and the footprint can then be deduced.



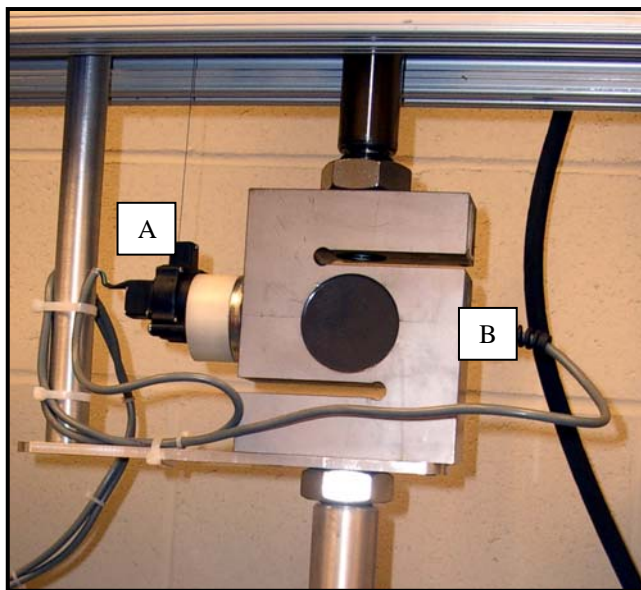
- A. Foot Print Test End Effector
- B. Tread Bond Test End Effector
- C. Stiffness Test End Effector



Sensors:

The stiffness testing machine relies on two sensors to generate data. The first is a linear transducer manufactured by Unimeasure, model number LX-EP-10. The transducer has a digital encoder wheel coupled to a steel cable. Movement in the cable results in a change in state of the encoder wheel. The transducer outputs a standard TTL quadrature signal that can be read by a digital counter or data acquisition hardware installed within a computer, as is our case. The transducer requires an excitation at least 30 mA at 5 volts. As in our case, this usually can be provided through data acquisition hardware. The LX-EP-10 has a 10 inch travel range and has a resolution of about 0.004 inches.

The second sensor is an S-beam load cell manufactured by Precision Transducers, model number ST-10,000kg. As in most S-beam load cells, this transducer relates force exerted upon it to a change in electrical resistance built within the cell. Circuitry in the load cell, namely a wheatstone bridge, translates the change in resistance to a voltage output. The ST-10,000 requires an excitation of at least 5 volts and a maximum of 15 volts. The voltage output is directly linked to the input voltage. Each load cell is calibrated and measured at the factory to precisely understand this relationship. For the ST-10,000 installed in the test machine, this particular load cell has been measured to output 2.001mV/V of input at the full weight. In other words, if we were to excite the load cell at 10 volts and place 10,000 kg of mass onto the load cell, the resulting voltage output would be 20.01mV. Precision Transducers guarantees linearity to within 0.017%. So if we place half the weight as before with the same excitation, the voltage output should be half as well. As with the linear transducer, the voltage output is measured with data acquisition hardware and the software translates the voltage measurements to corresponding forces. Resolution of the load cell is limited by EMF noise in the surrounding environment. As a result, the minimum resolution is approximately 35 pounds.



A. Linear Transducer

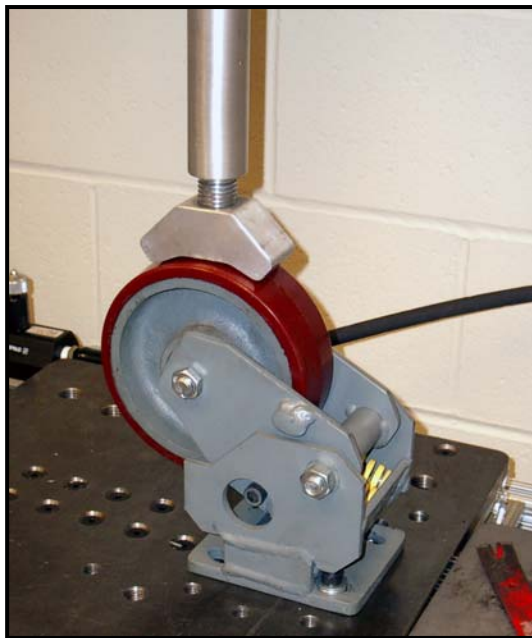
B. S Type Load Cell

Sources of Error:

Errors in data acquisition can come from a variety of sources. Mechanical structures and elements deflecting or creeping under load result in erroneous readings from the linear displacement transducer. For example, the aluminum support beams were design to handle loads of greater than 20,000 pounds. However, at that load maximum deflection was calculated to be less than 1/16 of an inch.

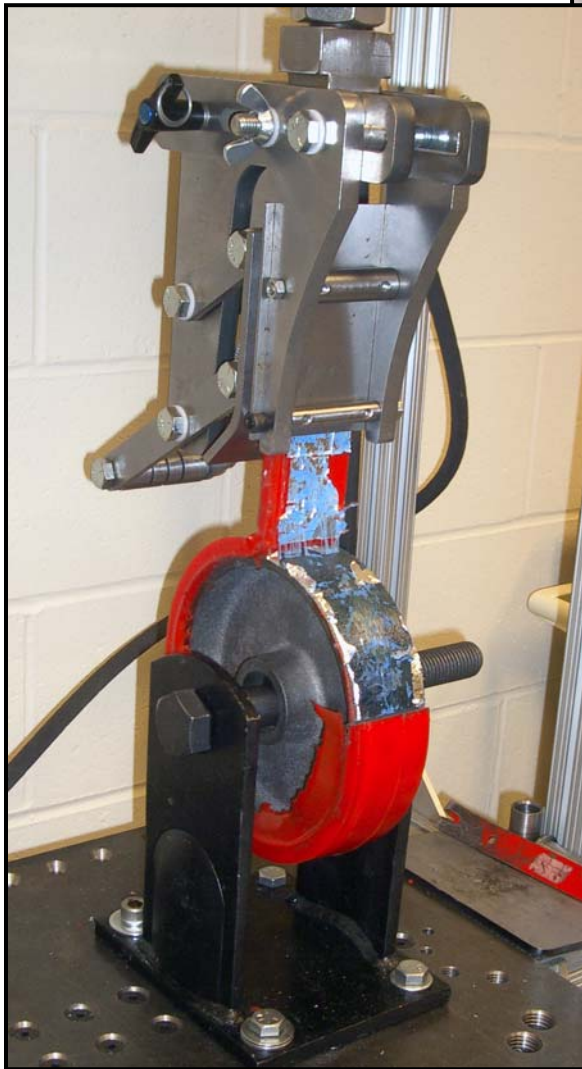
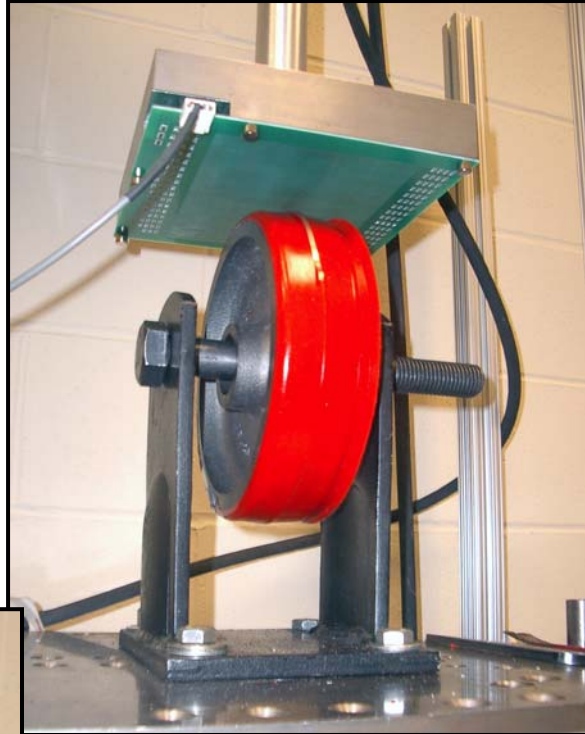
The most common source of error comes from the sensors themselves. For example, the linear encoder is simply an optical rotary encoder which rotates as a spool of wire is pulled. The wire is returned to the spool through a torsional spring. However, if the return travel velocity is too large, slack develops on the wire resulting in erroneous displacement data. We thus limit the traveling speed of the hydraulic piston to no more than about 1 inch per second. The load cell is affected by ambient electrical and magnetic noise. The low voltage signal that the load cell outputs can often times be masked by electrical noise. By filtering the data through software low pass filters and time averaging, we can mitigate these effects. However, the minimum resolution of the load cell is about 35 pounds.

Test Procedures:



For the most part, the static test machine is very straight forward to operate. In order to perform stiffness measurement of spring loaded casters, a sample caster is bolted onto the machine base, the plunger end effector is attached to the load cell end, the software is initialized, and the operator plunges the piston downward to displace the spring loaded caster. The computer based measurement system will continuously record both the displacement data as well as its corresponding load. The data that results is plotted onto a graph depicting a force vs. displacement graph. The stiffness or spring constant of the spring loaded caster can then easily be extracted by determining the slope of that graph. Below is an example of such a graph. One should note that not only can the stiffness of the spring loaded caster be understood from this graph, but we can also observe the linearity of the spring constant, in other words understanding if and how the spring constant changes as the arm of the spring loaded caster is displaced. We can also observe the amount of preload within the springs of the caster and measure its total travel length.

In order to run the footprint measurement tests, the footprint end effector is mounted on to the test machine. The custom designed circuit board is attached onto the bottom of the mount plate and the input/output cable is connected. A voltage signal is transmitted through this cable to the PC data acquisition system and allows the computer to interpret the signals and record a corresponding foot print value. In operation, the plate is lowered onto the test wheel, which has a piece of cooper tape attached to its circumference. As the wheel makes contact to the circuit board,



the copper tape creates an alternate circuit of essentially zero ohmic resistance. In other words it shorts out certain traces in the circuit board. As a result, the total ohmic resistance is reduced and circuitry on the board creates a corresponding, linear change in voltage output. As the wheel flattens with additional load, more traces are shorted, thereby changing the output voltage continuously. The results thus show a continuous correspondence between load and footprint.

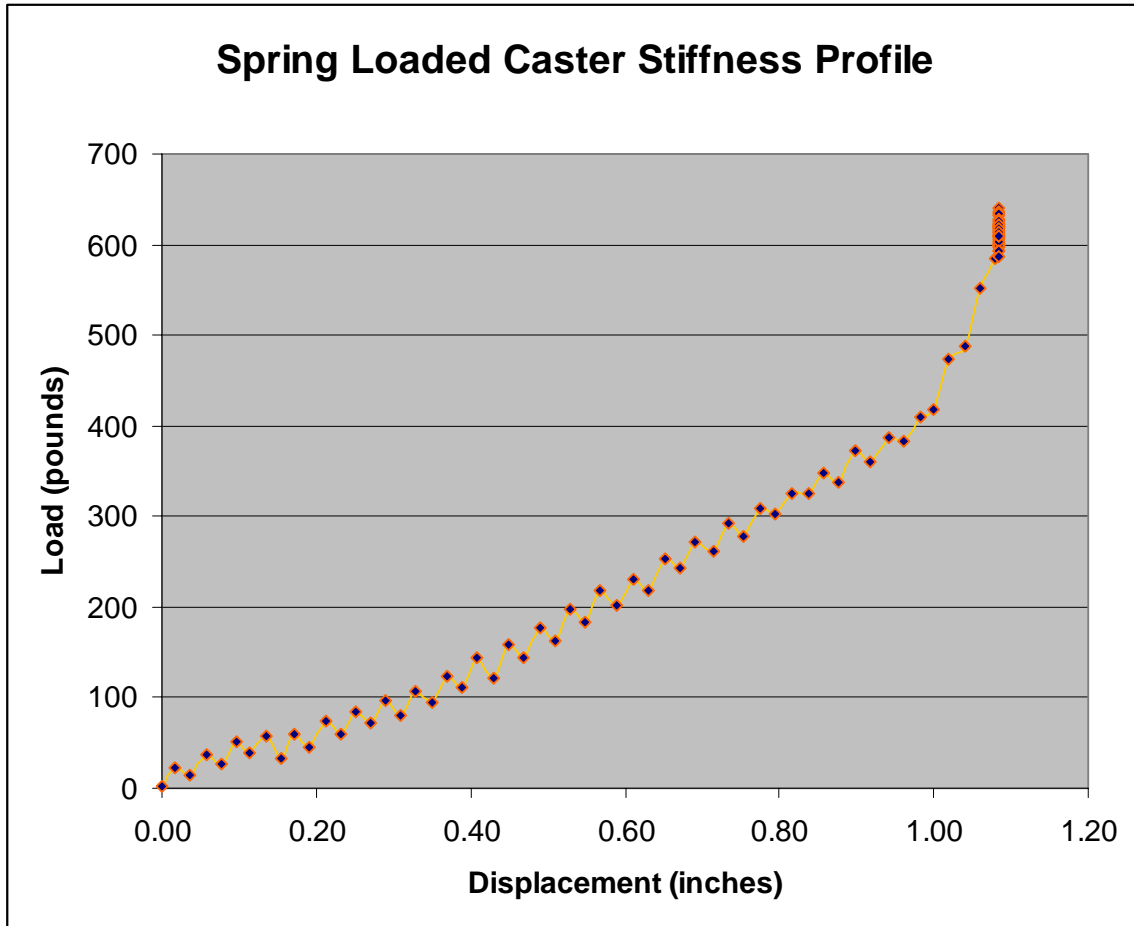
For a pull test, another end effector is used, that of our custom designed clamping jaws. An elastomer tread wheel is specially prepared such that a bond is prevented from forming on about a 6" section of the tread. This creates a tongue which the jaws of our end effector can easily grab. The wheel is loaded onto the test machine and the tongue is inserted into the jaws. With the software initialized, the hydraulic piston begins to pull on the tongue and, as in the other



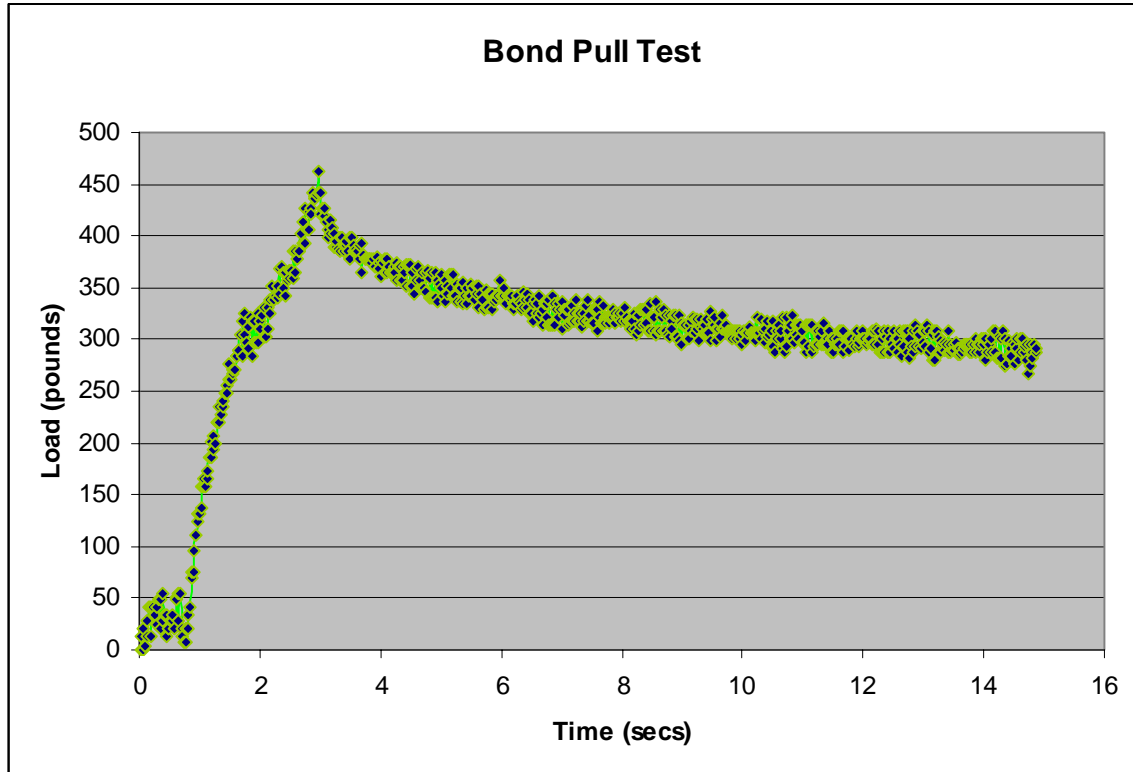
tests; the force/displacement data is recorded. The bond test software is modified to also record the maximum force. This gives us an understanding of the peak force to tear the bond as well as the sustained force to continue to progress the tear along the wheel/tread interface. Understanding both values is important to correctly evaluate the quality of adhesion between the tread and wheel.

Results:

A sample graph of a spring stiffness test is shown below. The graph shows the relationship between the force applied the movement or displacement in the spring loaded caster. From this graph we can note that there is insignificant preloading in the springs and that the stiffness profile is fairly linear for a majority of its travel. At the very end of its travel the springs exhibit a small amount of non-linearity right before it hits the stops. The total travel is about 1.08 inches and its spring constant is approximately 400 pounds/inch. The saw tooth waves of the graph show the noise in the data. As mentioned before, the resolution in the load cell is approximately 35 pounds.



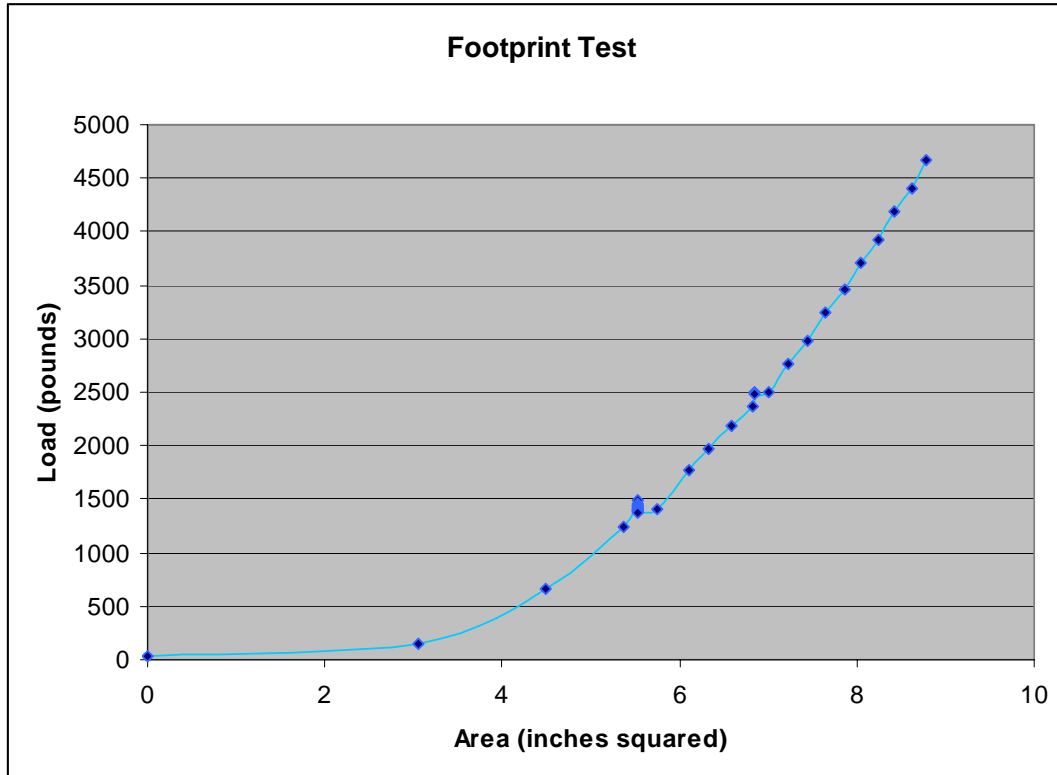
A sample data set of a bond pull test is graphed below. The results show that as the tread tongue is pulled the resulting force increases quickly to reach a maximum, in this case about 450 pounds. At the maximum, substantial bond failure occurs. The tread delaminates from the wheel hub. Tear is initiated and once started, the graph shows that it requires far less force to continue. We see that as time progresses, the force reaches an asymptotic value, in this case about 300 pounds. This is the force required to continue to tear the bond. Below this amount, any tear will not continue to grow. It is important to understand both the maximum and the sustained force values. It is important that bond quality be adequate such that large sudden shear forces do not rip the tread away. Such an understanding would come from measuring the maximum pull force. Likewise, it is equally important that wheels with pre-existing microscopic levels of porosity are able to withstand daily wear which is capable of growing micro-cracks into larger tears. Such would be evident by understanding the sustained level of force needed to continue the tear.



Lastly, sample data is presented in the graph below depicting the relationship between the applied load and the resulting footprint. As one would expect, the relationship is highly non-linear just as the load is being applied. A small increase in force results in a large increase in footprint. However, as the urethane tread is compressed close to its strength limits, the load to footprint relationship exhibits far more linearity. Testing for this relationship allows us to provide customers with an exact load to footprint relationship. While there exists formulas which can predict such a relationship, they



are prone to error because they require certain material properties, such as the modulus of the tread material to be precisely known. It is commonly understood that the modulus of elastomers are highly strain dependent and thus difficult to pin down to one single number. Testing is the only way to guarantee a precise understanding for the load to footprint relationship.



Conclusions:

With a firm understanding of the static characteristics of our casters, CCI now has the ability to scientifically guarantee quality and consistency over their broad and often custom designed product line. This static test machine has played an invaluable role in quantifying tread bond quality, spring stiffness consistency, and wheel footprint characteristics. The static test machine has been an important part of CCI's testing laboratory. Coupled with our dynamic caster simulation machine, which is able to subject our casters to a number of real world conditions, including various loads, speeds and floor conditions, the static test machine provides a clear and comprehensive picture of our products performance.

Questions and comments are always welcomed. Please contact Dr. Elmer Lee elmerlee@casterconcepts.com about our testing facilities. Also, Mr. Ben Miles, our chief engineer, would be happy to help with caster applications and products. He can be reached at bmiles@casterconcepts.com.