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MEASUREMENT METHOD
FOR POLYSTYRENE

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Final Report

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ABSTRACT

A flexible Pi scale measuring band and a measuring wheel system, both capable of measuring the diameters of 24- to 42-inch polystyrene billets with an accuracy of ± 0.001 inch and repeatability of ± 0.001 inch, have been developed to measure the shrinkage of soft, porous polystyrene foam billets.

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SUMMARY

A flexible band gage and a measuring wheel system were developed to accurately measure the shrinkage of soft, porous polystyrene foam billets. The band gage with etched Pi scale was designed to measure 24- to 42-inch diameters to the nearest 0.001 inch with repeatability within ± 0.001 inch. Smaller versions of the flexible band gage can be applied to other parts currently measured by vernier calipers or micrometers. The measuring wheel system, based on a similar British "Electric Diadem" system, was designed to make equally refined measurements with the added benefit of digital readout and more automated operation. Where significant temperature variations were not anticipated, an aluminum-adiprene measuring wheel provided better repeatability than the metal (Kovar) wheel in the measuring wheel system.

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DISCUSSION

Accurate measurement of the shrinkage of polystyrene foam billets is vital to determine the completeness of the stabilization process. Conventional measurement methods are not suitable because of the soft, porous surface of the foam.

After being molded, polystyrene foam billets were subjected to heat treatment to drive off part of the pentane residue. This treatment accelerated the natural shrinkage and reduced the internal stresses within the billet, resulting in greater dimensional stability to parts machined from the billet.

Measurement methods considered included a flexible band gage, optical systems, and fixed measuring pads. The measuring wheel principle was added after a British report revealed other benefits for this type of device.

FLEXIBLE BAND GAGE

Early experiments showed that a standard Pi tape would make the required diameter measurements if uniform tension could be maintained during the measurement, and if some means of accurately positioning the tape on the part could be provided. Uniform tension of the tape had to be maintained during usage since the low density of the material would allow compression of the surface according to the forces applied. Because a direct comparison of measurements taken before and after heat treatment shows the effects of the process, conditions under which the measurements are made must be identical to be meaningful. A second problem involved the alignment of the Pi tape on the part squarely and in the same location for comparative measurements. A Negator (constant force) spring proved capable of providing constant tension, regardless of the amount of extension from its reel. Arrangements were made to order the spring and to have a Pi tape scale etched on it in the materials engineering laboratory.

An attempt to wrap the spring onto a billet revealed that the spring took on a crowned configuration when reeled off the spool, and consequently would not lay flat against the part surface. The Negator spring was then used to drive a constant torque motor which, in turn, powered a reel for a conventional Pi tape. Design of a rotating table to hold the billet and appropriate arms to support the motor-reel mechanism, and the use of the Pi tape, solved the problem of alignment of the tape on the part. Support arms of different lengths provided selection of three optional measuring positions on the part. The prototype device accommodates billets from 24- to 42-inches in diameter. Figure 1 shows the completed device in use. Figure 2 is a close-up view of the constant torque motor and Pi tape reel assembly.

Figure 1. Flexible Pi Scale Measuring Band Positioned on a 42-Inch Polystyrene Billet

Figure 2. Close-Up View of the Constant Torque Motor and Pi Tape Reel Assembly

Table 1. Billet Measurement Data

Operator Number	Measurements (in.)				
	1	2	3	4	5
Small Billet					
1	32.069	32.069	32.069	32.069	32.070
2	32.068	32.069	32.069	32.068	32.068
3	32.068	32.068	32.068	32.068	32.068
4	32.068	32.069	32.069	32.069	32.069
5	32.069	32.069	32.069	32.069	32.069
Large Billet					
1	41.938	41.940	41.940	41.939	41.939
2	41.939	41.939	41.939	41.939	41.939
3	41.940	41.940	41.940	41.939	41.940
4	41.939	41.939	41.940	41.939	41.939
5	41.940	41.939	41.940	41.940	41.940

Suggested improvements for subsequent models include a Negator spring with slightly less tension. The prototype spring provided a tension of 10 pounds, but 6 pounds is recommended since this is the value used for Pi tape calibration. A motor drive with reversing motor for turning the table would add a degree of automation to the device, and also eliminate potential damage to it in case of accidental release of the Pi tape support arm while the tape is extended. Also, telescoping support arms would provide infinite positioning options for the tape.

A smaller version capable of measuring from 8 to 18 inches in diameter would be useful for measuring numerous parts where present inspection techniques employ vernier calipers or micrometers. The average diameter could be determined in less time and with greater accuracy with the flexible band type gage. Table 1 shows actual data taken by five different operators during measurements of two billets of polystyrene.

MEASURING WHEEL SYSTEM

Based on a British technical report describing an "Electric Diadem" system, a similar system using the measuring wheel principle was developed. Five major items comprise the prototype device: the measuring wheel, the precision rotary encoder, the trigger device, the digital counter and display, and the rotary table for supporting and rotating the part to be measured. Auxiliary items include a power supply for the encoder and trigger, a stand for the assembly, and appropriate supports for holding and positioning the measuring wheel on the part. Figure 3 shows the assembly of the prototype device. Figure 4 is a close-up view of the measuring wheel.

In principle, a wheel of precisely known diameter is held in contact with the part and is rotated by it. The wheel is mounted to the shaft of a precision rotary encoder, a device that generates electrical pulses as its shaft is turned. The pulses are counted and registered on the digital counter. The number of revolutions made by the measuring wheel for one complete revolution of the part represents the circumference of the surface. If diameter measurement is preferred, it can easily be accomplished by selecting the appropriate combination of measuring wheel diameter and encoder output pulses per revolution. The start and stop of the counting is controlled by the trigger device which consists of a light-sensitive diode and a thin strip of reflective material.

To obtain a measurement, the part is placed on the table of the fixture. The measuring wheel is positioned to the desired location on the part, and the spring is adjusted to provide approximately 8 ounces of contact force by the wheel. The rotary table is turned on and the counting starts when the reflective strip on the underside of the table passes over the trigger device. Counting continues until the reflective strip passes over the trigger the

Figure 3. Prototype Measuring Wheel System

Figure 4. Close-Up View of Measuring Wheel and Rotary Encoder

second time. Repeated measurements can be made by pressing the reset button on the counter after each completed count. If the control knob is set, the counting will continue for 10 revolutions and the digital display will show the average of 10 individual measurements.

Inertia of the wheel and encoder are insignificant because counting does not usually start until the wheel has made several revolutions. Also, effects of slippage are minimized by using a low torque, optical encoder.

The most critical item in the system is the measuring wheel diameter. Unless the wheel is made of a material having a low thermal coefficient of expansion, temperature variations could cause the diameter to change and could cause a measurement error.

The prototype wheel was designed to exert low contact pressures in measuring polystyrene billets. Expected temperature variations are minimal in the area where the measurements are made. The prototype wheel was made of aluminum with an adiprene tire molded on it. The outside diameter was ground size after molding. Adiprene provides an excellent gripping surface with good wear qualities, while offering enough resilience to prevent damage to fragile surfaces. Figure 5 shows the details of this wheel.

A second wheel was constructed of Kovar, a material with a low thermal coefficient of expansion, and was laminated to the required thickness (Figure 6). The finished wheel was extremely heavy but was used in several tests at room temperature. When the wheel was tested on a metal ring, slippage occurred. The surface of the wheel was then sand-blasted, which reduced the slippage but caused approximately 0.00075-inch increase in the wheel diameter. The measuring error introduced by this diameter increase was 0.004 inch on the 35.745-inch ring.

Contact forces as much as 25 pounds were used in the "Electric Diadem" system. With forces in this range, slippage of a metal wheel on a metal part is reduced to a minimum, even with a polished wheel surface, according to the British report. The Bendix prototype would not accommodate forces this high because the wheel was mounted directly on the encoder shaft. Modification of this part of the system to include a separate bearing for the measuring wheel would be relatively simple, and is recommended for application of on-machine gaging or for measuring metal parts with a wheel having a low coefficient of expansion.

Evaluation of the system included measurement of an aluminum ring with two different wheels at varying contact forces. The ring was then measured by the precision measurement department, and the results compared. Table 2 shows the data from these measurements. Figure 7 is a plot of the force versus the diameter reading for the aluminum-adiprene wheel.

Figure 5. Diagram of Aluminum-Adiprene Wheel

Figure 6. Diagram of Kovar Wheel

Figure 7. Contact Force Versus Diameter Reading for Aluminum-Adiprene Wheel

Table 2. Diameter Comparison of Measuring Wheel Method Versus Conventional Methods

	Disk* (in.)	Ring A (in.)	Ring B (in.)	Ring C (ID) (in.)
Precision Measurement**	35.3978	35.7472	31.9968	28.9897
Aluminum-Adiprene: 8 oz	35.4023	35.7482	31.9959	28.9887
Kovar: 8 oz	35.3878	35.7415	31.9922	
*Edges of disk reported to be out-of-parallel by Precision Measurement				
**Data corrected for temperature differences				

Tables 3 and 4 show the range of 10 readings with the adiprene wheel at various forces and the range of six readings with the Kovar wheel respectively. Repeatability of 10 measurements with the adiprene wheel was within 0.002 inch at 4 ounces, and within 0.001 inch at 8, 12, and 16 ounces. The Kovar wheel repeated within 0.003 inch at 8, 12, and 16 ounces.

A major problem encountered during the checkout involved electrical interference resulting from transient pulses in the power line. Extraneous pulses originate when other electrical equipment on the same circuit is switched on or off. If the measurement is underway during this switching, the extra pulses are also counted, causing an error in the reading. Filters in the power supply improved the condition, but the problem was not solved until shielding was added to the cable which carries the encoder signals to the counter.

The measuring wheel system is useful for measuring inside as well as outside diameters. A slight modification of the support arm would make the prototype device more adaptable to inside measurement. The measuring wheel and the electronic apparatus work equally well for either measurement.

Future application for the measuring wheel system includes normal on-machine gaging. A more sophisticated version of the system could generate feed-back signals to provide the necessary correction to the original NC command so that the cutting tool could be positioned according to the actual part size.

Table 3. Measuring Wheel Contact Force Versus Diameter Reading For Aluminum-Adiprene Wheel (Ring A)

Diameter Reading	Contact Force			
	4 Ounce (in.)	8 Ounce (in.)	12 Ounce (in.)	16 Ounce (in.)
1	35.744	35.748	35.751	35.751
2	35.744	35.748	35.750	35.752
3	35.744	35.749	35.750	35.751
4	35.745	35.748	35.750	35.752
5	35.744	35.748	35.750	35.752
6	35.746	35.748	35.751	35.752
7	35.745	35.748	35.750	35.752
8	35.745	35.748	35.750	35.752
9	35.745	35.748	35.751	35.752
10	35.745	35.749	35.750	35.752
Average	35.7447	35.7482	35.7503	35.7518

Table 4. Measuring Wheel Contact Force Versus Diameter Reading For Kovar Wheel (Ring A)

Diameter Reading	Contact Force		
	8 Ounce (in.)	12 Ounce (in.)	16 Ounce (in.)
1	35.741	35.740	35.739
2	35.741	35.740	35.740
3	35.740	35.739	35.739
4	35.742	35.742	35.741
5	35.743	35.740	35.739
6	35.742	35.740	35.739
Average	35.7415	35.7402	35.7395

Figure 8. Schematic Diagram of Measuring Wheel Device

Figure 9. Wiring Diagram of Measuring Wheel Device

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