Round-robin evaluation of thickness test methods for gray cast iron

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Testing of gray cast iron samples indicates that instrumentation and calibration methods are important in obtaining accurate and consistent measurements of thickness. Hartford wedge and eddy current calibrations gave the best results.

Ultrasonic thickness testing of vessels, tubes, and piping to measure for corrosion and wear is perhaps the most common nondestructive test method used in the pulp and paper industry. With the "pulse-echo" ultrasonic instrument that is universally used for testing, the time from the transmit pulses to the return echo is a function of specimen thickness and sound velocity. When the ultrasonic instrument is used on samples of known thickness and the same acoustic velocity as the material being tested, it can be calibrated to gauge the component thickness.

The technology of ultrasonic thickness testing is not as well proven for gray cast iron as it is for steel. This is because the acoustic velocity of cast iron varies substantially from one casting to another, whereas the velocity in steel is essentially constant. Thus, a casual approach to ultrasonic gauging of cast-iron dryer shells may result in errors of 50–60% or even more.

To achieve the best results when ultrasonic gauging cast iron, the acoustic velocity must first be determined. This may be performed by matching the unknown iron with one of similar metallurgical characteristics (and thus same acoustic velocity), or by using special test instruments to measure the acoustic velocity in the unknown iron. One instrument used to perform the acoustic velocity test is called the "Hartford wedge."*

During 1988 and 1989, the TAPPI Corrosion and Materials Engineering Committee conducted a round-robin survey on thickness testing of cast-iron dryer shells. The objectives of the survey were to determine:

1. The types of ultrasonic equipment used by nondestructive testing agencies for dryer thickness testing
2. The accuracy of testing that might be achieved by various testing means.

*The Hartford wedge is manufactured by the Harisonic Research Center, 470 West Ave., Stamford, Conn.

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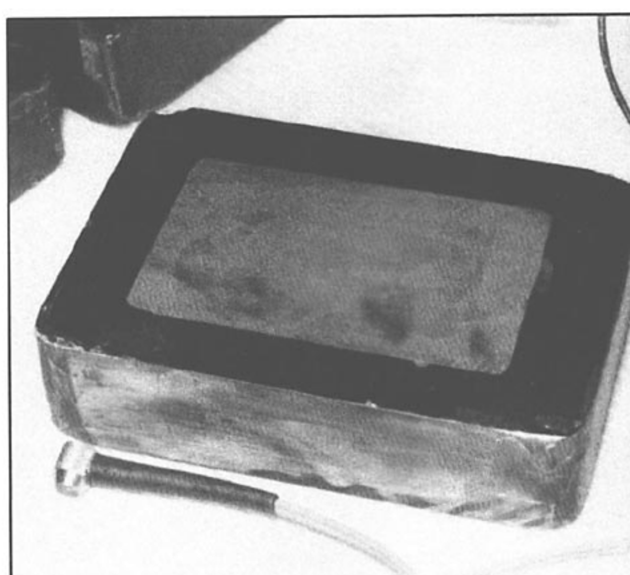
1. The cast-iron samples used for the survey were embedded in a plastic resin so only one side was accessible for measurement.



This report summarizes the results of tests by 17 companies that participated in the program.

Preparation of cast-iron test blocks

Ten cast-iron samples with varying properties were collected for use in the survey. The round-robin samples were machined from actual dryer shells, of which eight did not meet Code specifications of the American Society of Mechanical Engineers (ASME) and two were Code dryers. Incidentally, foundries began producing paper machine dryers to ASME Code specifications in the 1940s, and the eight non-Code samples were pre-1940.

Each cast-iron sample was prepared by machining to a working size of 75 mm by 125 mm. Thicknesses varied from 10.9 mm to 35.4 mm. The thicknesses of the samples were accurately measured prior to embedding them in a

I. Thickness and properties of round-robin iron samples

Sample	Thickness mm	Thickness in.	Tensile strength MPa	Tensile strength ksi	Brinell hardness	Approx. acoustic velocity, m/sec × 10^3	Year of manufacture
A	18.64	0.734	114.4	16.6	137	4.41	1921
B	17.17	0.676	86.1	12.5	115	4.32	1921
C	22.66	0.892	144.7	21.0	186	4.66	1923
D	10.87	0.428	147.4	21.4	162	4.31	1903
E	14.99	0.590	100.6	14.6	132	3.84	1912
F	35.43	1.395	179.1	26.0	201	5.05	1953*
G	30.05	1.183	117.1	17.0	156	4.74	1930
I	16.08	0.633	96.5	14.0	141	4.09	Unknown
J	18.59	0.732	115.1	16.7	169	4.32	1923
K	32.26	1.270	321.8	46.7	196	4.74	1987*

*ASME Code dryer (Class 40).

plastic resin. Thus, only one flat surface of each iron sample was exposed for testing (**Fig. 1**). Each cast-iron sample was also tested to determine the tensile strength, hardness, and acoustic velocity. **Table I** shows the relevant information for each of the dryer shell samples used in the round-robin test. For convenience, values are given in both millimeters and inches and in both megapascals (MPa) and thousands of pounds per square inch (ksi).

Results

Qualification of technicians

Nondestructive testing by the ultrasonic method requires that the technician be well trained in the field. Recommended Practice No. SNT-TC-1A of the American Society for Nondestructive Testing provides guidelines for minimum training in the ultrasonic discipline. All but one of the 17 participants responded that the technicians performing the work held either Level II or III certification for ultrasonic testing.

Instrumentation and calibration method

Table II lists the instrumentation used by the participants. All used basic ultrasonic pulse-echo instruments for the test. However, several variations in the equipment appeared to be relevant to the results obtained. The variations were:

1. Use of cathode ray tube or digital instruments
2. Type of search unit (i.e., frequency and size) and whether a special velocity sensor was used (Hartford wedge)
3. Whether an oscilloscope was used to assist in interpretation of the signal from the Hartford wedge.

A primary factor influencing the results was the method of calibration used. The Hartford wedge measures the velocity of the test piece as the first step, and the thickness is measured as the second step. Seven of the participants used the Hartford wedge, and one participant reported that the "wedge principle" was used, but not the Harisonic wedge. The other systems relied on indirect means of calibration, such as selection of a separate cast-iron calibration block that was believed to be representative of the unknown sample. Two participants used the eddy current method to compare the unknown samples with known cast-iron standards. Five participants used a single standard of cast iron that was thought to be representative of the unknown irons. One used the velocity for cast iron selected from a reference table, and one used a carbon steel reference block.

Thickness test results

The thickness reported for each test block by the participants is listed in **Table III**. The actual thickness is also shown.

Analysis and ranking of methods

The data for each participant were evaluated by determining the *percent average absolute deviation* from actual thickness for the group of ten samples. This value was small when the results were the most accurate. Another measure of the accuracy of the participants is the *percent standard deviation* for the thickness measured in the group of samples. This is a measure of the consistency of testing, with a small value of standard deviation indicating the most consistent participants. The results of the analysis are listed in Table III, and the data are summarized in **Table IV**. Ranking is shown in order from the best results to the worst.

Discussion

The analysis indicated that the most accurate measurements in cast iron can be achieved only when the variations in acoustic velocity are measured. Only the Hartford wedge principle (eight participants) and eddy current (two participants) methods provided a possible means to discriminate between the various acoustic velocities in the assortment of samples. The remaining seven participants who calibrated using available cast-iron test pieces, or who

II. Instrumentation and calibration methods used by participants, in order of ranking from best to worst

	Ultrasonic instrument			*Search unit*				
	Manufacturer	*Model*	*Type*	*Manufacturer*	*Model*	*Size, in.*	*Freq., MHz*	*Calibration and remarks*
1	Harisonic	M-1	Digital	Harisonic	Hartford wedge	...	1.5	Dual-channel oscilloscope used to assist interpretation. Calibrated Hartford wedge to blocks of stainless steel, brass, steel and Class 30 cast iron.
2	Nortec	NDT-131D	CRT and digital	1. Harisonic 2. Nortec	Hartford wedge VM 12-1	...	...	Hartford wedge search unit used with Nortec instrument. Used Hartford wedge for all samples except E. Calibrated on carbon steel per Harisonic procedure. Sample E measured by conventional L-wave method after calibrating instrument on a cast iron block with Hartford wedge velocity similar to E.
3	Sonic FTS	Mark I	CRT	1. KB Aerotech 2. Blatek	Dual element Dual element	0.875 0.5	3.5 2.25	Eddy current method used to compare unknown samples to a group of five known cast iron samples of Grades 20-50.
4	Sonic	Mark I	CRT	Harisonic	CR01085	...	1.0	Used 1930 Pusey-Jones dryer shell for calibration standard.
5	Harisonic	M-1	Digital	Harisonic	Hartford wedge	...	...	Preliminary scans with Nortec 131D and USL48 CRT units. Used standard Hartford wedge kit and calibration blocks for measurements.
6	Harisonic	M-1	Digital	Harisonic	Hartford wedge	...	1.0	Dual channel oscilloscope used to assist interpretation. Calibrated Hartford wedge to steel step block 0.5-1.5 in. supplied with wedge kit.
7	Krautkramer-Branson	DM scope	CRT and digital	Krautkramer	...	0.5	1.0	Calibrated using standard velocity reference table (1.9 in./sec × 10^5).
8	Krautkramer-Branson	303B	CRT	Krautkramer-Branson	Delta	1.0	1.0	Calibrated to Class 30 cast iron.
9	Harisonic	M-1	Digital	Harisonic	Hartford wedge	...	...	Calibrated Hartford wedge to a cast iron standard block.
10	Panametrics	22DLHP	Digital	Panametrics	M106	0.5	2.25	Calibrated to Class 40 cast iron standard.
11	1. Sonics with Model 120 2. Harisonic	MK1 with thickness analyzer M-1	CRT and digital Digital	Panametrics Harisonic	V106 Hartford wedge	0.5 ...	2.25 ...	Used wedge method to determine velocity; calibrated MK-1 to above velocity for final measurement.
12	1. Krautkramer-Branson 2. Stresstel	USIP-11 T-Mike	CRT Digital	Harisonic KBI	Dual element Dual element	1.0 1.0	1.6 1.0	Used "wedge principle."
13	1. Sonic 2. Panametrics	Mark FTS 26DL	CRT Digital	Panametrics Panametrics	V104 D797	... ...	2.25 2.0	Eddy current method used to compare unknown samples to two known iron samples reported to be Grades 30 and 40.
14	Krautkramer-Branson	USL38	CRT and digital	Harisonic	Hartford wedge	...	...	Hartford wedge search unit used with USL38. Used wedge manufacturer's calibration procedure with carbon steel block.
15	JB Engineering	CM-621	Digital	JB Engineering	CM50-50	...	...	Calibrated using cast iron dryer shell of known thickness.
16	Krautkramer-Branson	USK-7 and USK35	CRT	Aerotech	Gamma	...	1.0	Calibrated to International Institute of Welding (IIW) carbon steel block.
17	Krautkramer-Branson	USL48	CRT	Aerotech	Delta	1.0	1.0	Calibrated on cast iron valve flange 1.375 in.

III. Actual thickness of test blocks and thickness measured by participants, in order of ranking from best to worst

	Thickness, in.										Average absolute deviation,[a] %	Standard deviation,[b] %
	A	*B*	*C*	*D*	*E*	*F*	*G*	*I*	*J*	*K*		
Actual	0.734	0.676	0.892	0.428	0.590	1.395	1.183	0.633	0.732	1.270	0	0
1	0.734	0.689	0.918	0.418	0.578	1.427	1.310	0.619	0.719	1.287	2.7	2.8
2	0.720	0.670	0.880	0.420	0.610	1.370	1.240	0.600	0.700	1.240	2.8	1.5
3	0.690	0.645	0.800	0.400	0.635	1.330	1.185	0.640	0.675	1.290	3.1	5.0
4	0.750	0.720	0.900	0.360	0.620	1.320	1.280	0.640	0.740	1.310	5.0	4.4
5	0.722	0.684	0.898	0.416	0.405	1.396	1.287	0.607	0.709	1.277	5.4	9.0
6	0.679	0.646	0.869	0.380	0.529	1.379	1.244	0.585	0.693	1.236	5.8	3.2
7	0.800	0.760	0.925	0.430	0.725	1.320	1.250	0.710	0.790	1.275	8.0	6.4
8	0.700	0.700	0.850	0.500	0.650	1.250	1.250	0.700	0.800	1.200	8.1	3.9
9	0.725	0.685	0.900	0.495	0.440	1.400	1.375	0.675	0.725	1.275	8.5	6.9
10	0.810	0.762	0.939	0.465	0.697	1.360	1.318	0.706	0.797	1.313	9.3	4.4
11	0.724	0.690	1.079	0.408	0.498	1.365	1.555	0.628	0.718	1.540	10.2	10.6
12	0.743	0.775	0.939	0.587	0.722	1.237	1.196	0.676	0.707	1.269	10.3	11.1
13	0.825	0.780	0.930	0.480	0.715	1.350	1.320	0.710	0.815	1.305	10.6	5.5
14	0.791	0.735	0.990	0.373	0.586	1.563	1.479	0.715	0.783	1.459	11.3	6.0
15	0.743	0.430	0.859	0.425	0.714	0.582	0.388	0.656	0.733	0.455	25.6	26.9
16	0.990	0.920	1.120	0.590	0.890	1.640	1.590	0.860	0.990	1.600	33.4	8.4
17	1.250	1.120	1.650	0.400	1.000	0.800	0.750	1.000	1.150	0.680	53.8	20.9

[a]Deviation equals the measured thickness minus the actual thickness. The average absolute percent equals the sum of the percent deviation for 10 samples divided by 10.

[b]Standard deviation percent was determined by calculating the standard deviation of the average absolute deviation percent for the 10 samples.

selected the velocity from a reference table, did well only when by chance the velocity selected was close to that of the test sample.

A rather large accuracy distribution was obtained for the users of the Hartford wedge. Subsequent interviews with the technicians revealed that calibration of the equipment can be tricky, especially if an oscilloscope is not used to observe the signal during the velocity test.

The eddy current calibration method is based on the principle that different metals respond differently to electromagnetically-induced currents. In this process, the technician attempts to compare the unknown test blocks to known cast-iron standards. The participant who used five known standard blocks obtained accurate results with reasonable consistency. The participant with only two standard blocks obtained inconsistent results.

Conclusions

The program provided good insight on current methods for thickness testing of cast iron. Selection of the instrumentation and calibration methods for the tests appeared to be a vital factor in obtaining accurate and consistent results.

The Hartford wedge, when used with an oscilloscope, produced the most accurate readings with average deviations of 2.7–5.8% of section thickness. The best results were obtained on the Hartford wedge by technicians who seemed to understand the system well and who could deal with the problems associated with calibration.

The eddy current method of calibration may be

IV. Summary of data from calibration methods shown in Table II, in order of ranking from best to worst

	Method	Average absolute deviation, %	Standard deviation, %
1	Hartford wedge (oscilloscope assist)	2.7	2.8
2	Hartford wedge with Nortec	2.8	1.5
3	Eddy current (5 samples)	3.1	5.0
4	1930 cast iron dryer	5.0	4.4
5	Hartford wedge	5.4	9.0
6	Hartford wedge (oscilloscope assist)	5.8	3.2
7	Velocity cast iron from reference table	8.0	6.4
8	Class 30 cast iron	8.1	3.9
9	Hartford wedge	8.5	6.9
10	Class 40 cast iron	9.3	4.4
11	Hartford wedge	10.2	10.6
12	"Wedge principle"	10.3	11.1
13	Eddy current (2 samples)	10.6	5.5
14	Hartford wedge with Krautkramer	11.3	6.0
15	Cast iron dryer shell	25.6	26.9
16	IIW carbon steel block	33.4	8.4
17	Cast iron valve flange	53.8	20.9

promising, especially if a good assortment of calibration standards is available.

Calibration using reference book values for acoustic velocity or a random sample of cast iron for the standard is risky and may produce testing errors of 50% or more of wall thickness. It is also important to assure that standard steel calibration blocks are not used when gauging cast iron because this will result in errors near 30%. The acoustic velocity of steel is greater than that for gray iron, and the actual thickness of the iron will be less than it appears.□

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