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Results of Acoustic Emission Tests on Halon Fire Bottles

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ABSTRACT

An acoustic emission tester for aircraft Halon bottles has been developed. The necessary load is applied by heating the bottles. Acoustic emission is monitored during the heating by six sensors held in position by a special fixture. This fixture was designed to fit spheres with diameters between 5 and 16 inches. A prototype has been undergoing testing in two commercial Halon bottle repair and test facilities. Results to date indicate that about 97 percent of the bottles tested show no indications of any flaws. The other three percent have had indications of flaws in non-critical areas of the bottles. All bottles tested to date have passed the hydrostatic test required by the DOT.

Keywords: Acoustic Emission, Halon 1301, Aircraft, Fire Extinguishers, NDT

1. BACKGROUND

The world aircraft industry employs spherical bottles containing pressurized Halon 1301 (CF_3Br) to extinguish engine and cargo hold fires. Current US Department of Transportation, (DOT) regulations require periodic testing of these bottles for structural integrity. Several bottles are shown in Figure 1. The only test method currently approved by DOT regulations is hydrostatic testing for inelastic expansion of the bottles. This test requires that the sealed bottles be opened, emptied, pressurized with water in a water bath, refilled with Halon 1301 and then resealed.

The production of Halon 1301 throughout the world was stopped in January 1994 because of its ozone depleting properties. At this time no substitute material exists which combines both Halon 1301's outstanding fire extinguishing effectiveness and low toxicity. The US airline industry has been granted an exemption by the DOT to continue using Halon 1301 through the year 2000. The cost of Halon from existing stores has rapidly increased even though all Halon from the bottles undergoing a hydrostatic test is recovered, refined and reused. A test of the bottle integrity which did not require removal

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of the Halon would save much time and expense for the worlds airlines as well as eliminating one source of loss of the worlds dwindling Halon 1301 supply.

In the past the DOT has granted exemptions to allow acoustic emission testing of gas cylinders on gas transportation trailers in place of the hydrostatic test. This procedure is now widely used throughout the United States. In this test, the cylinders are monitored with an acoustic emission system while subjected to an over pressure of 110% of their maximum working pressure. This is done during the normal filling procedure. An extensive testing program has been able to set failure criteria for these cylinders. The extension of an acoustic emission test to aircraft Halon bottles would appear to be a natural.

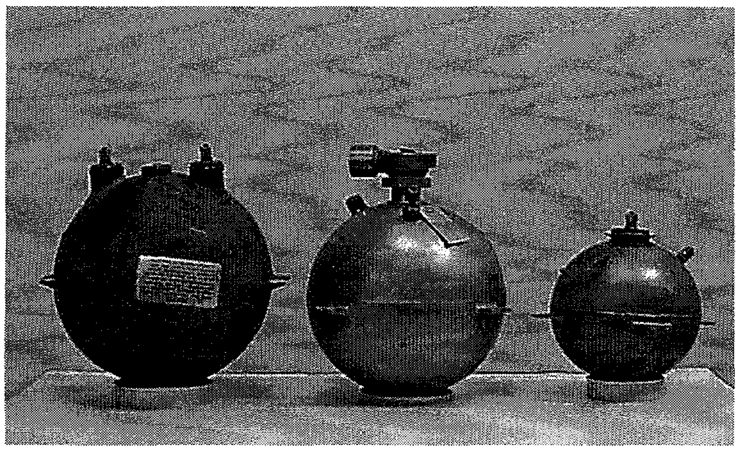

Figure 1. Halon bottles

2. PRINCIPALS AND NOMENCLATURE OF ACOUSTIC EMISSION

Acoustic emissions are transient acoustic waves generated by a sudden change in the local stress field in a material. Of primarily interest in this application is the microscopic growth of a crack in a metal wall of a pressure vessel. Increasing the pressure in a vessel increases the stress field in the walls. A crack will start to grow when the local stress exceeds the local strength of the material at the flaw. A crack produces a stress concentration at its tip. When an applied stress causes a crack advance, this will usually cause a decrease in the local stress field and the crack will stop. As the applied pressure is increased the crack will grow intermittently. Each advance of the crack is accompanied by an acoustic emission. These waves propagate throughout the material until they reach the surface. Here they can be detected by a piezoelectric sensor.

The acoustic emission test used for the aircraft fire extinguisher bottles is called a source location test. An acoustic emission source is the crack advance or other event in the material which generates an acoustic wave. This wave travels until it reaches and excites a sensor. The excitation of a single sensor is called a hit. An event can produces hits on multiple sensors. The arrival time is the instant when each sensor is first excited. The location of the source on the bottle can be calculated from the arrival times of the wave at different sensors and the knowledge of the coordinates of those sensors and the radius of the bottle.

3. DESIGN OF AN ACOUSTIC EMISSION TEST

The main problem in designing a safe, practical acoustic emission test for Halon bottles was developing a method to increase the pressure in the bottles. The best method to increase the pressure in permanently sealed bottles is to heat the bottle and its contents. Most of the currently used Halon bottles have been restricted by their manufacturers to use at temperatures below 160°F. A temperature of 145°F will produce a pressure in most Halon bottles about 30% above the bottle pressure at 110°F, a temperature that the industry estimates will seldom be exceeded in normal service. Therefore heating a Halon bottle to 145°F will exceed the 110% criteria and will provide a valid test. The lack of significant emission is proof of a sound bottle which can be returned, unopened, to service.

The Federal Aviation Administration (FAA) and the Air Transport Association has sponsored the development of such an acoustic emission test for Halon bottles. The spherical bottle is held in a special fixture where six spring loaded sensors are positioned on the bottle in a fixed geometry. The sensors are mounted on the end of rods which extend along radii of the sphere. Adjusting the distance of the sensors from the center allows the fixture to accommodate spheres from 5 to 16 inches in diameter. This covers a large majority of the Halon 1301 bottles in current use. The fixture is then mounted in an industrial oven where heat is applied to the bottle. The acoustic emission system is programmed to locate the emission sources on the sphere. It will determine whether these sources are scattered at random or clustered into small regions, which would indicate crack growth. The computer is used to maximum effect, not only determining if indications of a serious flaw are present but also controlling the oven and printing out a report.

4. DESCRIPTION OF THE SYSTEM

We have built a prototype system which uses the new Physical Acoustic Corporation AEDESP-32/16 acoustic emission cards in a 486-66 personal computer for the acoustic emission system and a Russell industrial oven. The oven has encased heating elements with a surface temperature limit of 800°F. This will prevent thermal decomposition of the Halon 1301 in the event of an accidental release. The oven air temperature is limited to a maximum of 200°F. Relays are installed in the oven to allow the computer to operate the heaters and circulation fan. The computer reads the skin temperature of the bottle using a thermocouple. Also incorporated in this system is an auto sensor test where each sensor is pulsed and the amplitude of the received signal is measured at all the other sensors. This test insures that all channels are working and that all of the sensors have good acoustic coupling to the bottle. Figure 2 shows the oven, fixture and acoustic emission system.

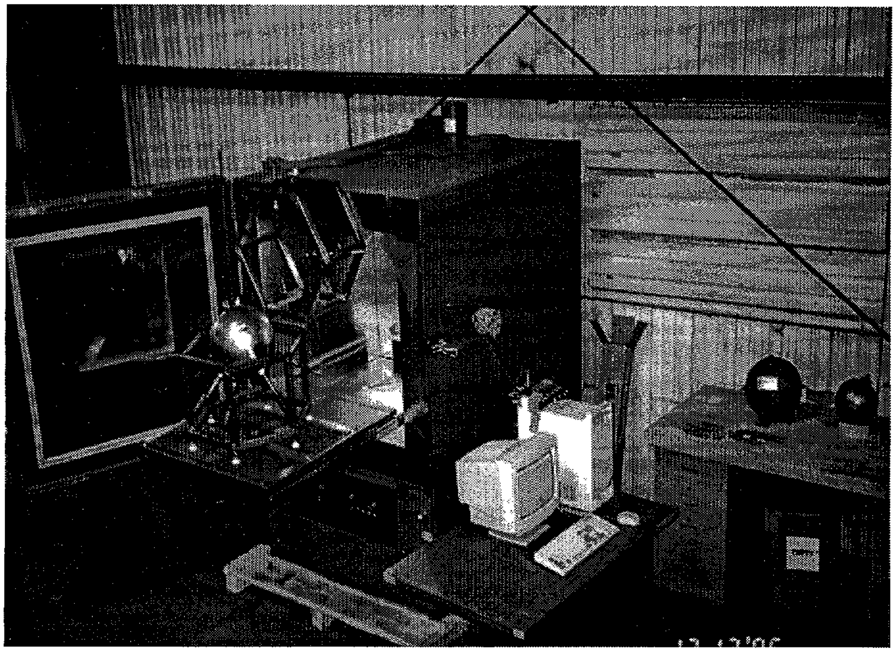

Figure 2. Halon bottle test system

To operate the system, the operator first loads the bottle into the fixture and attaches the thermocouple to the lower skin of the bottle. Next the bottle identification is entered into the computer. When this is verified, the computer starts the auto sensor test. If the average of the peak amplitudes of all signals received by each sensor lies within 3 dB. of the average of the signals received by all the sensors, the test is passed. If the test is failed, the operator is instructed to reseat the sensors and try again. After the auto sensor test is passed, the system turns on the oven and circulation fan and starts taking data. When the bottle wall temperature reaches 150°F, the heaters and fan are turned off and the bottle sits for five minutes to allow the halon inside to reach equilibrium with the bottle wall. The equilibrium temperature is usually between 145 and 150°F. At this point, the computer notifies the operator to remove the bottle from the oven. Throughout the test, the computer is attempting to calculate the locations of every event. It then checks each located event to see whether it is a member of a cluster or whether it starts to form a cluster with another event. If a serious cluster forms, for example containing more than fifty events with an average count of over 200 counts per event, the computer will shut off the heater and circulating fan and signal the operator to either remove the bottle from the oven or open the door to allow the bottle to cool. A brief report is printed at the end of every test identifying the bottle and stating either that it passed or failed or that the test is indeterminate. Currently, a bottle passes if no clusters with ten or more located events are seen. Failure is defined as the occurrence of a cluster containing 50 or more located events and 75,000 or more counts. An indeterminate result is defined as the acorns of at least one cluster containing 10 or more events. These definitions may change as more test results are obtained.

5. EXPERIMENTAL RESULTS

The first experiments conducted with the new acoustic emission system and spherical location program were performed on several bottles which had been removed from service by visual inspection. None of these bottles appeared to have a serious flaw. All ports were sealed except for an inlet and outlet pressure fitting. The bottles were filled with water and pressurized. One of the bottles had been dented with a hammer by airline mechanics to insure that it would not be reused. Pressurization to 1200 psi popped out most of the dent. The AE system detected 17 events during this pressurization, 13 of them being located within the three inch circle which contained the dent. This bottle had a 70^{o}F fill pressure of 600 psi and an ultimate design pressure of 2400 psi. The acoustic emission from the dent occurred between 400 and 840 psi. The bottle survived pressurization with no other significant emission to 1900 psi. After the prototype tester was built and checked out, it was installed in the Walter Kidde Co. testing facility in Wilson N.C. Tests were run on halon bottles returned by air carriers for repair or testing. Because these bottles were owned by customers and some had tight scheduling requirements, not all of the desired NDT testing could be performed on questionable bottles. All bottles tested with the acoustic emission system subsequently passed the hydrostatic test. One Hundred and fifty-two bottles were tested at this facility. These bottles covered a range of volumes from 86 to 1400 in3. The shell materials were Nitronic-40 steel (21-6-9), Almar steel and 4130 steel. About 1/3 of the bottles were painted. The test times varied with bottle volume and material, with painted bottles heating more slowly than bare bottles. Over all, the average time to perform a test was about 26 minutes per bottle. The first test of the day usually takes around 45 minutes as the oven must be heated as well as the bottle. These times are included in the average time.

The results of these tests are given in table 1.

TABLE 1

Summary of Bottle Tests at Walter Kidde Co.

8 bottles	No acoustic emission seen.
50 bottles	Random AE Hits but no Located Events.
62 Bottles	Random numbers of AE hits and one or more located events.

28 bottles	Random numbers of AE hits and located events. Clusters with 6 or less events in a cluster.
4 Bottles	Relatively high numbers of AE hits and located events. At least one cluster containing 14 or more located events.

The last 4 bottles listed in Table 1, not only showed large clusters but also had large numbers of located events. Two of them showed a cluster covering a doubler plate with a fixture lug mounted on it. These plates were about the same thickness as the bottle wall and were attached to the wall with a fillet weld around the edge of the doubler. One bottle showed a weld that was too steep and had discoloration on the inside of the bottle. While the bottle passed the hydrostatic test the fillet weld was probably cracked with the crack running parallel to the bottle wall. The other bottle had an x-ray taken of the fillet weld. A small tungsten inclusion was found in the weld. This is an ideal crack initiation site and the relative strain between the wall and the doubler plate during the heating cycle probably caused some microcrack growth.

The third of these bottles had the cluster located in the region where a port had previously been removed and a new port with a larger and thicker base welded into the bottle. Unfortunately, the weld could not be examined from the inside and we could only speculate that there was some slag or other minor imperfection in it. The last bottle had two clusters with over a hundred events near the outlet ports and pressure switch. No problems were seen when the welds were x-rayed. The source became apparent when it was realized that the bottle had been refitted with a new shield for the pressure switch. Instead of welding the shield to the bottle, it had been attached with set screws. The clusters were located around the pressure switch shield. The expansion of the bottle had caused a relative movement of the set screws, producing the acoustic emission.

6. CONCLUSIONS

The acoustic emission tester has shown its ability to detect small flaws in halon bottles. None of the flaws seen yet are serious enough to reject the bottle. Therefore no rejection criteria has been set at this time. While it is hoped that there will be a few truly bad bottles tested, it may be that none will be seen. Then, based upon the current data, the criteria can be set such that the tester will pass all bottles showing no clusters of acoustic events containing more than 10 events. Hydrostatic tests would be required only for bottles with clusters of events above this level. While not using acoustic emission as the sole test, it would save having to open around 97 % of the bottles sent in for retesting. Since the Halon bottle tester can be operated in the hanger or repair facility, only the remaining 3% of the bottles would have to be sent out for retesting. This alone would result in a considerable savings for the airline industry as well as helping to conserve the world supply of Halon 1301.

The final step in this project will be for the Air Transport Association to request an exemption from the DOT which would allow its members to use the acoustic emission test as a filter for the hydrostatic test. At this point, the Halon Bottle Tester will be turned over to a manufacturer to be commercialized and sold to interested parties.

7. ACKNOWLEDGMENTS

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8. APPENDIX, TECHNICAL DESCRIPTION

The acoustic emission system is based upon the Physical Acoustics Corporation AEDSP-32/16 digital acoustic emission board. Three boards are mounted in a 66 MHz 486 computer. These boards contain a digital processor with a 16 bit word and a maximum digitization frequency of 8 MHz. The large dynamic range of the 16 bit word (up to 90 dB.) allows triggering at a very low signal level without losing high amplitude data. The system is triggered at a 25 dB level (17 microvolts out of the sensor). The boards use dedicated signal processing chips to calculate various AE signal parameters in real time from the digital record. In this application, we record the following parameters for each AE hit: The test time to within 1/4 of a microsecond, the AE count, the peak signal amplitude, the signal rise time, the signal length, the area under the voltage time curve (called variously signal strength, "energy" or marse), and finally, the digitized waveform for each hit. This digital record contains 2048 words digitized at a 4 MHz rate and is recorded for every hit on each sensor. This allows the test engineer to go back and examine acoustic waveforms when the test results are not clear cut. The detectors are PAC nanno 30 sensors. These have a response peak between 300 and 350 KHz. The 40 dB preamplifierfrequency band pass is set at 250 to 1200 KHz. This restriction to higher frequencies is necessary to reduce the effect of low frequency sound waves reverberating through the Halon inside the bottle. Unfortunately the bottles are not smooth spheres. Fill ports, discharge ports and mounting lugs are welded onto the bottle. These cause distortions of the acoustic waves traveling along the bottle wall. The largest amplitude signals are usually flexural waves which are easily distorted as they pass under a mounting or positioning lug or through the base of a port. The lugs are often mounted on a doubler plate which is fillet welded to the surface of the sphere. At the relatively low signal amplitudes (35 to 50 dB) seen in these spheres, the distortion of the waves can produce triggering on either the extensional or the flexural portion of the wave, making the calculation of the exact source position difficult. To achieve reasonably accurate location on detected signals, only over-determined data sets are used in the calculation (an event where the emitted acoustic wave excites 4 or more sensors). A non-linear least squares program was written in Fortran to calculate the most probable location of the event on the sphere. It was then modified by PAC to work with their hardware. This location program first tries the extensional wave velocity (0.205 inches/microsecond). If that does not produce a good fit to the data, the flexural velocity (0.118 inches/microsecond) is tried. The computer ignores the event if it cannot locate the source position with a relatively good fit to the data by using one of these two wave velocities. Approximately 80% of all the events are located. This percentage approaches 100% as the peak amplitude of the wave exceeds 300 microvolts out of the sensor.

To estimate the significance of the events an algorithm was written which searches for spatial clusters of event sources. A cluster is arbitrary defined here as all events which fall within a circle on the surface of the sphere. The radius of this circle is 15 degrees of the arc of a great circle on the bottle. The center of the cluster is the average coordinates of all the included locations. In addition, an average value of an acoustic emission parameter for the cluster (currently, the average ringdown count from the first hit sensors of all members of the cluster) is calculated as an indicator of the severity of the cluster. The 15 degree radius corresponds to a circle about 3 inches in diameter on a eleven inch diameter sphere. This cluster size was based on data from a flawed bottle. Extended testing indicates that it is a reasonable choice for the spherical Halon bottles used in the air fleet.