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Apparatus for Impact-Fatigue Testing*

R. E. Schramm,** R. L. Durcholz,** and R. P. Reed**
Institute for Basic Standards, National Bureau of Standards, Boulder, Colorado 80302

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A standard impact machine was extensively modified to allow the measurement of the response of specimens to repeated, controlled impact pulses. This equipment enables one to vary the temperature (76-297 K), specimen geometry (uniaxial, biaxial, triaxial stress systems), and load levels. At stress levels in the neighborhood of the yield stress, on the order of 10,000 impact cycles are needed to fatigue specimens to fracture. Strain rates achieved are moderately high, of the order of 1000 min^{-1}, which conveniently form intermediate data between tensile (max. of about 100 min^{-1}) and explosive straining data (about 6000 min^{-1}). Contrasted to standard fatigue tests, no constraint is placed on specimen elongation and only unidirectional stresses are imposed. Typical impact-fatigue results for AISI 310 stainless steel are presented.

Key words: Cryostat; fatigue; impact; low temperature; mechanical property equipment; stainless steel.

1. Introduction

In many low temperature applications such as in the transportation of dewars or in the transfer of cryogenic liquids through pipe, system components experience periodic sudden jolts or loads. Prediction of expected life of these components can best be accomplished by testing controlled specimens under repeated impact loads which approach values up to the yield load. Such a test, then, can be described as impact-fatigue, as the specimen eventually fractures in a manner similar to conventional fatigue fractures.

To perform such tests, a standard commercial impact machine was extensively modified. These modifications resulted in an apparatus that could repeatedly apply sudden loads in the range 0 to 1800 kg for the long periods sometimes required for specimen fracture. Additionally, the specimen chamber was insulated to allow temperature environments from 76 to 297 K. Our paper describes this new equipment.

A standard Riehle model PI-2 [1] impact testing machine was available. This machine has three hammer sizes, 15, 30, and 60 lb (6.8, 13.6, and 27.3 kg) and the hammer drop is continuously adjustable from 0 to 48 in (0 to 1.3 m). Our impact-fatigue life determinations, however, would require a frequency greater than 20,000 in some cases so it became obvious that the single cycle operation for which this machine was designed was not feasible. We designed major modifications to automate the repetition, to allow tests to be conducted at cryogenic temperatures, and to permit the use of specimens in a great variety of configurations. Stress pulses are applied to the specimen in one direction, while the conventional fatigue tests are typically either "push-pull" with alternating tensile and compressive forces or flexure with alternating applied bending forces. Another feature of the impact-fatigue test is that the specimen is not constrained with respect to specimen strain.

2. Modifications

Figure 1a is a schematic view of the impact-fatigue tester. A 1/6 hp, 1725 rpm electric motor is geared to

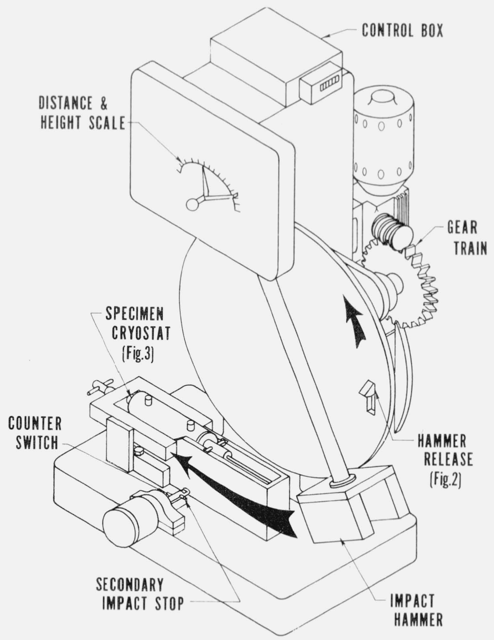

FIGURE 1a. *Schematic view of impact-fatigue tester.*

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**Cryogenics Division, National Bureau of Standards, Boulder, Colo. 80302.

[1] The use of trade names in this paper in no way implies endorsement or approval by NBS and is included only to define the experimental procedure.

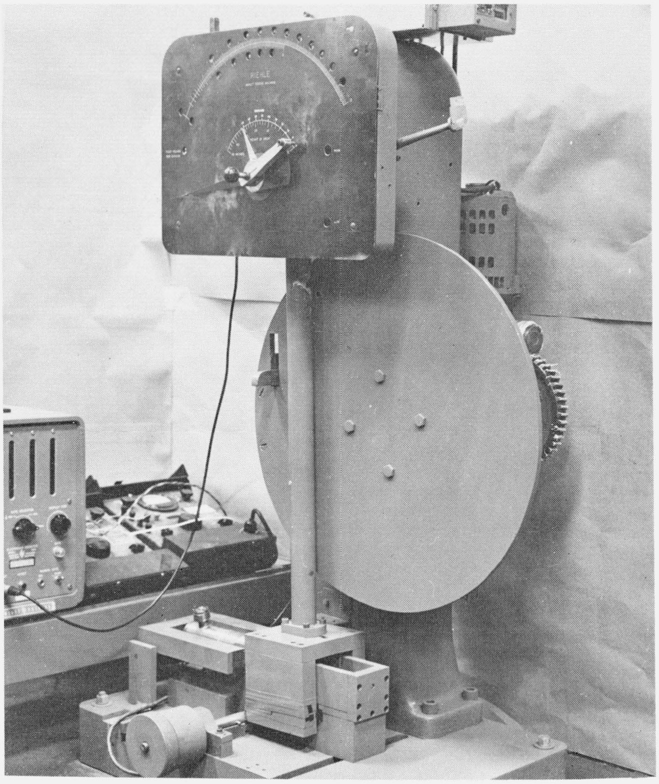

FIGURE 1b. *Photograph of impact-fatigue tester.*

rotate a 24-in diam wheel at 7.3 rpm. The shaft and bearings which support this wheel are clamped to the upright part of the impact machine frame by U-bolts. A brass hammer release arm protruding through the outer edge of this moving wheel serves to pick up the hammer and raise it to a predetermined height. At this point, the trip arm

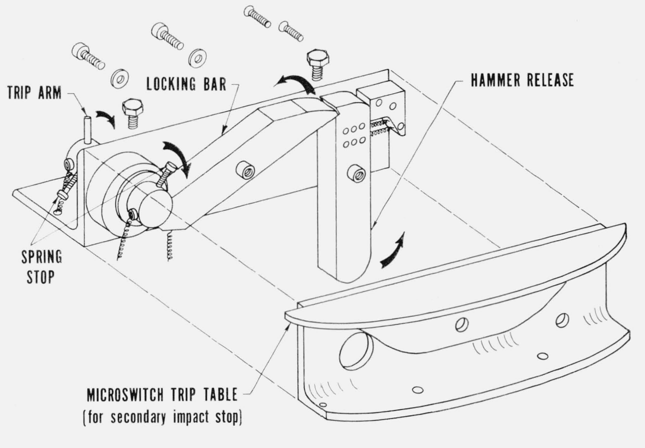

FIGURE 2. *Impact hammer release mechanism.*
The trip arm is rotated by a stationary block fixed at the desired position behind the 24-in wheel. This allows the hammer release to fall back under the hammer weight. Springs then return the mechanism to a locked position.

(figure 2) encounters a block which is supported behind the rotating wheel. The trip arm rotation causes a cam motion which swings a locking bar out of position, allowing the hammer release to simply fall back under the weight of the hammer. A second trip block is at the top of the wheel's revolution to insure that the system does not bind there as it passes the pendulum shaft. After each trip, springs pull the release bar back into a locked position to repeat the cycle.

The standard anvil on the base of the impact machine has been closed off on the right end to serve as the fixed point to which the right specimen pull rod is anchored, either directly or through a load cell (figure 3). The left pull rod passes through a three piece impact yoke assembly held together by eight ¼-in stainless steel bolts. The hammer impact is absorbed by this yoke which transmits it to the specimen, since it is free to move in a right-left direction on four rollers. When the sample breaks, the yoke moves to the left and allows the hammer to strike a switch on the base which removes electrical power from the whole system.

A solenoid system prevents secondary impact by the recoiling hammer (figure 1a). This stop is a ¾-in round bar which rides in a brass bushing inserted into a drilled hole in the impact machine. When this bar is in the fully inserted position, the impact hammer cannot swing past it to strike the yoke. A portion of the bar has a flat depression ground into it so that when the solenoid is activated and the bar partially withdrawn from the anvil the hammer may pass by freely. A switch on the stationary wheel near the block that trips the hammer release mechanism controls the power to the solenoid. As the trip table (figure 2) passes by this switch, the secondary stop is removed from the impact hammer path. By the time the hammer has recoiled, power has been removed from the solenoid and springs have pushed the stop back into position. A pin through this bar operates another switch to advance a cycle counter.

Wherever possible, the springs in the hammer-release mechanism were doubled, so if one fails during a test the second will continue to function until repairs can be made. It is important to use high quality steel springs to minimize difficulty due to breaks; soft, tempered springs were found more reliable than high strength units. Since this modification results in a much higher repetition rate than was originally intended, the welds between the pendulum shaft and fittings on both ends were reinforced.

3. Cryostat

The cryostat used for 76 K tests consisted simply of a 2-in diam PTFE rod, 7 inches long, with a 1-in bore through the center. The specimen pull rods are supported and

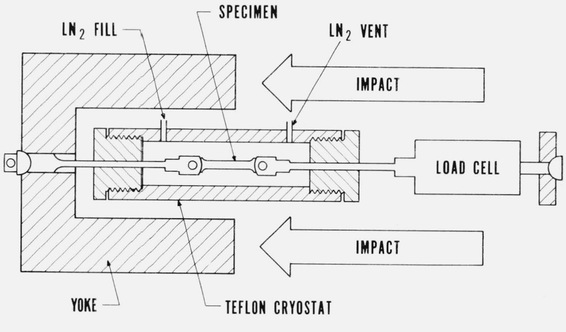

FIGURE 3. *Specimen impact system.*

centered by PTFE end caps screwed into the main chamber (figure 3). Rubber O-rings in both of these caps served as an initial seal around the pull rods to minimize the loss of liquid nitrogen. However, in cooling to 76 K, the PTFE contracts considerably and then serves as the main seal. Because of this great contraction, it is necessary to check for free movement of the pull rods when they are at test temperatures. Two small holes in the side wall serve for filling with liquid nitrogen and venting. A liquid flow of about 6*l*/hr was generally used to maintain temperature. At room temperature this cryostat was still used to assure the proper positioning of the sample.

For 195 K tests, a slight modification of this system was employed. Instead of the small holes in the side wall for filling and venting nitrogen, a 1×4 in panel was removed. A polystyrene foam box was attached to act as a reservoir for the powdered dry ice used to fill the cryostat. Consumption in this case was about 0.2 kg/hr.

4. Discussion

We used a load cell specially constructed to withstand sudden impacts and a high speed recorder to measure impact loading. When using the 30 lb (13.6 kg) hammer, the impulse time is about 2ms. Load cell response (figure 4) indicates a damped ringing, but this is a characteristic of the load cell. While the specimen probably does vibrate in the uniaxial direction, our system is incapable of measuring the compressive forces it may experience, but they are believed to be very small.

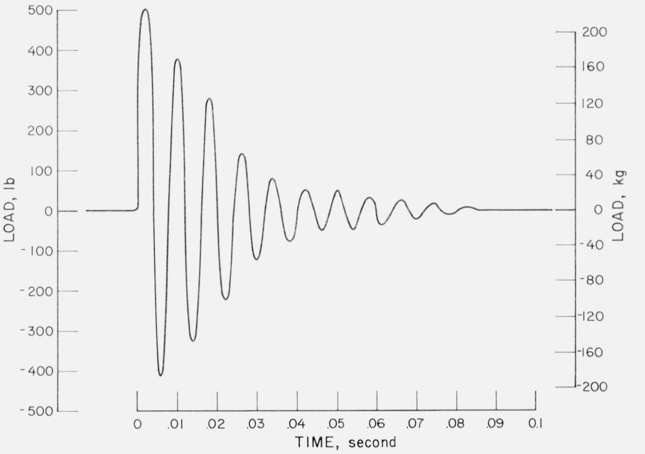

FIGURE 4. *Time response curve recorded by load cell and high speed recorder.*

During the progress of a test the specimen undergoes plastic strain. This allows the yoke to move in the direction of motion of the impact hammer. Thus, by measuring the position of the yoke frequently during a test, it is possible to determine specimen strain as a function of the number of cycles. Naturally, this function depends on variables such as material, temperature, and applied pulse. Figure 5 illustrates a typical curve of strain versus number of cycles for an AISI 310 stainless steel specimen. Initially, the specimen undergoes considerable strain but, after sufficient work hardening (several hundred cycles), its length becomes nearly constant.

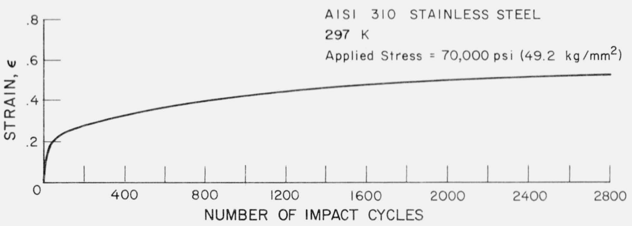

FIGURE 5. *Specimen strain during impact-fatigue life.*

Since each cycle corresponds to a 2 ms impulse time, the coordinate giving the number of cycles is also a time coordinate and its slope gives the strain rate. With our experimental conditions, the maximum initial strain rate was 2100 $\min^{-1}$. This is conveniently intermediate between the maximum strain rate in tensile tests of about 100 $\min^{-1}$ and the approximate lower limit[2] in explosive straining of 6000 $\min^{-1}$.

From the strain readings and load calibration, a typical stress-strain curve may be constructed. Figure 6 shows

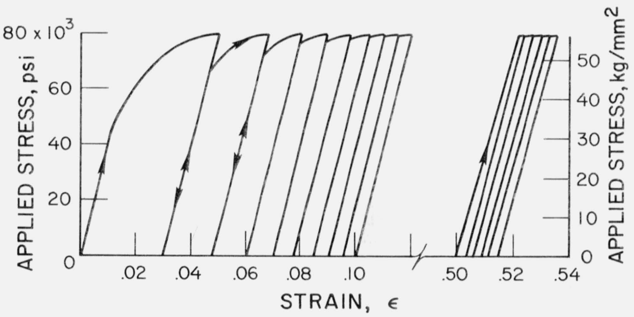

FIGURE 6. *Typical stress-strain curve for AISI 310 stainless steel showing repeated impact cycles at 297K (1 kg/mm² = 9.8 × 10⁶ N/m²).*

Compressive stresses due to recoil of specimen upon itself are very small and not shown.

this curve for AISI 310 at 297 K. The stress used to construct this curve is the engineering stress, i.e., load divided by original area. This stress level is constant throughout the test.

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[2] E. K. Henriksen, I. Lieberman, J. F. Wilkin, and W. B. McPherson, Metallurgical Effects of Explosive Straining, in Symposium on Dynamic Behavior of Materials (ASTM Spec. Tech. Pub. No. 336, 1963), p. 104.

By varying the height of the hammer (stress amplitude), a typical fatigue (S–N) curve of stress level versus number of cycles to failure may be obtained. The shape of such curves for AISI 310 at 297, 195 and 76 K, as shown in figure 7, is very similar to those obtained by conventional fatigue tests in which the high strain rates are not achieved and either the load or specimen deflection amplitude is held constant.

Any specimen configuration, limited only by length (about 5 in), may be measured. In practice, we have measured both uniaxial (tensile), biaxial, and triaxial (notch tensile) specimens of both AISI 304 and 310 stainless steels at 76, 195, and 297 K. These test results will be published later.

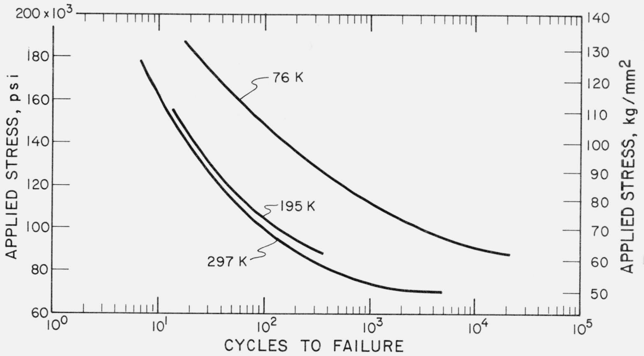

FIGURE 7. *Fatigue life curve for AISI 310 at 297, 195, and 76 K.*

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