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The stress analyzer, which contains two X-ray sources positioned 60° apart, can determine residual stress automatically. Here, author Weinman positions a sample for analysis.

Determining Residual Stresses Rapidly

By ERIC W. WEINMAN, JOSEPH E. HUNTER, and DOUGLAS D. McCORMACK

Called Fastress by its developers, a new X-ray analyzer can measure residual stresses in 20 sec. Its use opens possibilities for monitoring heat treating, cold forming, welding, shot peening, grinding, and other production processes.

X-RAY DIFFRACTION is one of the best methods for determining residual stresses, but conventional techniques take time. To answer the need for more speed, GM engineers have developed an automatic device. Called the Fastress analyzer, it can measure a residual stress of the tensile or compressive type in 20 sec.

Theory of Stress Measurement

When metal is stressed in tension, distances between atomic planes widen in the direction of the applied force and contract in a direction normal to it. These movements, of course, reverse when the metal is compressed. Since changes in atomic spacing constitute strain, and strain is proportional to the stress, we can determine residual stresses by ascertaining the extent of these changes. This is done by measuring angles at which X-rays are diffracted by the atomic planes.

The theory is that the magnitude of residual stress is proportional to the difference in positions of diffraction peaks for atomic planes parallel to and at an angle to the specimen surface. To measure stress, then, we must determine these positions when the sample is irradiated with X-rays striking at two different angles.

Using X-Ray Diffractometers

Because conventional diffractometers have one X-ray source and one detector, the technician makes scans at two angles, one at a time, to obtain two readings for diffracted intensity against diffraction angle. If recorded diffraction peaks are sharp, peak positions can be read directly from the intensity curve, and the stress calculated from a formula.

Mr. Weinman is associate senior research metallurgist and Mr. Hunter is senior research metallurgist, Metallurgical Engineering Dept., Research Laboratories, General Motors Corp., Warren, Mich. Mr. McCormack staff engineer, New Departure-Hyatt Bearings Div General Motors Corp., Sandusky, Ohio.

But if the diffraction peaks are broad (as they ıre for hardened steel), they will not be recorded ıt their true positions. Then the technician generally letermines the correct positions by taking three or nore intensity counts on each diffraction peak, correcting the counts for angle-dependent factors ınd locating the peaks by mathematically fitting a ymmetrical curve to the corrected intensity points.

A "two-point graphic method," originated by the GMR Metallurgical Engineering Dept., can be used o locate the true peak position directly from broad liffraction peaks. In this method, the technician uperimposes overlay curves (which are propor- ional to the combined correction factors) on the ecorded peak. On this curve, all points have equal corrected intensities. Thus the two points where hat curve crosses the curve of recorded intensity ıre of equal corrected intensity. Midway between hese two points lies the true position of the peak. Jse of this method reduces the time required for tress analysis to about 15 min. Also, and most mportant, the method provides a way to locate peak positions automatically.

How the Automatic Unit Works

Shown in Fig. 1 is a schematic of the automatic unit. Note that two X-ray sources placed at different angles simultaneously irradiate a common area of the sample. The device also has two sets of detector tubes; the output of each set drives a null-seeking mechanism that locates two points of equal cor- rected intensity on each peak. Corrections for angle- dependent factors are made electrically so that out- puts of the two detector tubes in a set are propor- tional to true intensities. At the null point, the true peak position lies midway between the two detector tubes. Potentiometers driven by the gear system at the end of each detector arm indicate the 0 and 60° peak positions directly. Because the difference between these voltages is proportional to stress, the recorder is calibrated to read in psi.

The unit also includes an instrument console which houses the stress recorder, stress calculator, circuitry for making corrections, ratemeters, and the power supply for the detector tubes. A con- ventional power supply unit provides power for the two X-ray sources. Ratemeters for each detector tube are electronically gated to be active when the appropriate X-ray source tube is powered. Each half wave of the rectified power source drives one of the X-ray tubes.

Figure 2 illustrates several measurements on three flat samples having different nominal residual stresses: 118,000 and 52,000 psi in compression and 20,000 psi in tension. Wide-beam irradiation was used, and specimens (mounted on a sliding fixture) were changed every 3 min. The range of recorded stress represents hunting (±10,000 psi range) of the servomechanisms, due in part to statistical fluc- tuations in the diffracted intensity. In each test, recorded over the 3 min period, the stress mean was repeated with an accuracy of ±2,000 to 3,000 psi; this compares favorably with the best laboratory accuracy on conventional diffractometers. (For this same degree of accuracy, the 21 stress measure- ments made in 63 min would require 10½ hr on conventional equipment.)

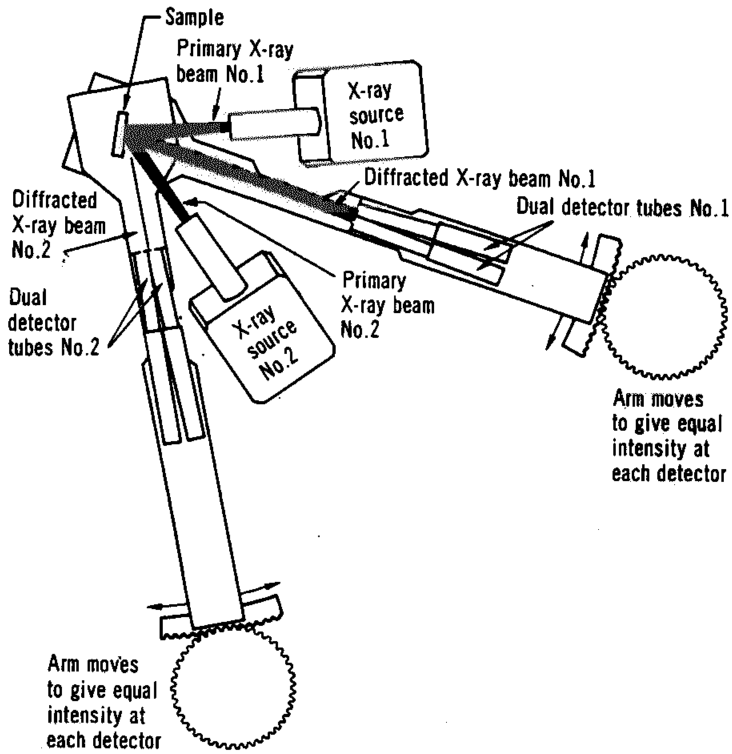

Fig. 1 — When the automatic stress analyzer is turned on, the X-ray beams strike the sample simultaneously and are diffracted in the gen- eral direction of their associated sets of detec- tors. Peaks of X-ray energy are located as arms move through the arcs to give equal intensity at each detector in a set. Because differences between the two voltages (indicated by the angle between the arms) vary with residual stress, the indicator is calibrated to read in psi.

These same three samples have been analyzed at the rate of 180 per hr with an accuracy of ±10,000 psi; both rate and accuracy would be acceptable for production monitoring. Even greater rates can be obtained with an accept-reject mode of operation because no time would be needed to drive servomechanisms. In such a unit, diffractometer arms could be fixed at positions which correspond to some minimum compressive stress, such as 20,000 psi. When a sample is placed in the beam, an almost instantaneous signal will indicate whether

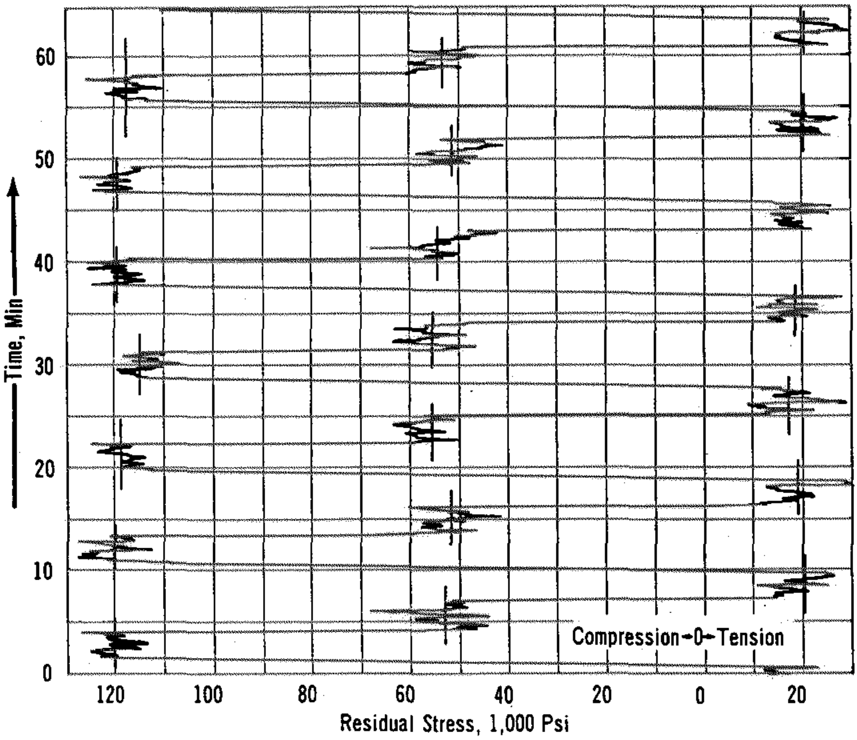

Fig. 2 — Repeated determinations of stress by the automated device indicate that results are quite accurate. (Mean stresses for 3 min of *readings are indicated* by short vertical lines.) The flat specimens had nominal stresses of 118,000 and 52,000 psi in compression and 20,000 psi in tension as determined by conventional diffractometer techniques.

the residual stress is above or below the preset level. Up to 700 parts could be checked every hour.

To measure tangential stresses on samples with small radii of curvature (such as ball bearings), the X-ray beam must be narrowed. Despite the lower incident and diffracted intensities, good accuracy is possible. As an example, in measurements on two 9/32 in. diameter balls, collimators produced coincident 0.060 in. spots of X-rays. Under these conditions, the range of recorded stress was a maximum of $\pm 13{,}000$ psi, and the mean was repeated with $\pm 4{,}500$ psi on one sample and $\pm 1{,}000$ psi on the second. Part of this difference in stress undoubtedly occurred because it is virtually impossible to measure stress on the same area and direction on the small balls each time.

Although developed primarily for measuring stresses in hardened (over Rc 58) steels, this device has been used on nonhardened steels with good results. With minor modification, the unit should also be capable of determining stresses on aluminum, chromium, and molybdenum.

Possible Applications

Engineers of the New Departure-Hyatt Bearings Div. have constructed the first production model of the analyzer and installed it in their central metallurgical laboratory. One of the initial applications is to monitor marstressed bearings to insure uniformity. (Marstressing is a process designed to impart residual compressive stresses to the surface layers of through-hardened parts.) In addition, carburized products can be checked for surface tensile stresses indicative of decarburization.

Plans are also underway to employ the device to monitor residual stresses generated during surface finishing operations. Using conventional diffraction techniques, New Departure-Hyatt engineers have been investigating the effect of surface stresses on the "superficial pitting" or "peeling" mode of rolling-contact fatigue failure. Application of the automated unit will enable them to sample and measure surface stresses on many more components. Samples up to 8 in. in diameter and several feet long can be handled in the present device. Full utilization of the unit's capabilities, however, are best realized with small parts which can be automatically positioned and removed.

The device could also be used to determine circumferential profiles of residual stresses on surfaces of bearing rings, with locations of specific values of stress marked for later correlation with sites of fatigue failure. Other potential applications include monitoring of grinding practices and heat treatment and grinding of critical cold-forming tools, analysis of service failures, and more rapid collection of data on development projects. In addition, periodic checks of tooling might help to detect rises in residual stress which could then be eliminated by design changes.