# RESIDUAL STRESSES IN COLD-COILED HELICAL AUTOMOMOTIVE SPRINGS

Most front-wheel-drive automotive suspension systems use helical springs. The process chosen to produce these is, like any other engineering dilemma, determined by quality, performance, price, environmental issues, etc. Ford Motor Company has developed a potentially cost saving cold-coiling process in which less time is spent treating spring metal at elevated temperatures. The pronounced residual stress pattern within the as-cold-coiled spring is undesirable for its unpredictable effect on fatigue and corrosion behavior, and Ford evaluates these stresses by X-ray measurements of the surface stress field along with modeling of the internal stresses. The success of these at-home procedures requires an independent verification of the actual residual stress field over the cross-section of the original wire stock. The only available well-established method for this is neutron diffraction, and that is where NCNR expertise comes into play.

Generally, there are two ways to coil a spring: hot coiling and cold-coiling. Hot coiling implies that the spring is wound from stock at or above the recrystallization temperature. The strength and fatigue resistance are controlled afterwards by an appropriate heat treatment. Cold-coiling means that the helical winding takes place at a low temperature after the spring has been hardened and tempered. Cold-coiling allows the high temperature heat treatments to take place on the bar stock, which is easier to handle than the coiled end-product. The resulting residual stresses can be essentially eliminated by a relatively low temperature tempering treatment following the cold coiling.

The idea is to measure the residual stress field in a number of specimens that represent various stages of the production process. Using neutron diffraction one can determine the effect of the prior processing on the residual stress state of that particular stage in the process. Of equal importance, these measurements can serve to verify well established elasto-plastic models that are being used to predict the formation of residual stress. Finally one can look for a way to correlate the residual stress at the surface to the stress field as a whole.

We have looked at three cold-coiled springs. The first spring is an as-cold coiled spring. The second one is cold-coiled followed by a relatively low temper. The third one is identical to the second one, but in addition to being tempered the spring has been compressed to the point where the length of the spring is equal to the number of windings times the wire thickness. After this the spring was allowed to relax. A small part of this torsion strain is in the plastic region, so this spring is slightly shorter than all the others. In the automotive industry this process is known as “bulldozing”.

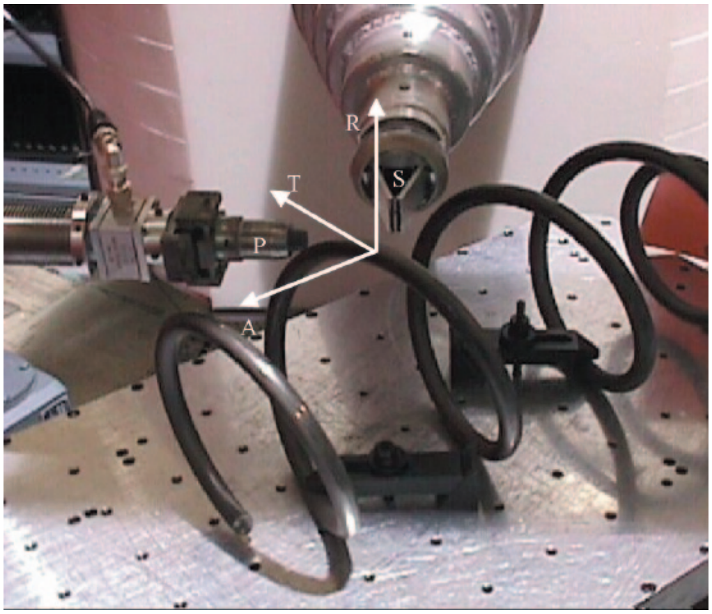


**FIGURE 1. Experimental setup. The three arrows indicate three directions of measured lattice spacing with respect to the specimen: A = axial, R = radial, T = tangential. In the current configuration, the spacing of planes whose normal is parallel to T is being measured. The sampling volume is defined by the primary aperture P and secondary aperture S, respectively.**

The measurements were carried out on the Double Axis system for Residual stress, Texture and Single crystal analysis (DARTS) at beam tube 8 (BT-8) in the NIST Center for Neutron Research. This instrument is specifically designed for residual stress measurements, and to that effect is equipped with very accurately positioned apertures as is shown in Fig. 1.

For these experiments the apertures were chosen to allow a sampling volume of $2 \times 2 \times 2$ mm$^3$. The residual stress in the three springs across the cross-section of the originally 14 mm thick wire stock was determined by detecting the diffracted monochromatic neutron intensity with a position sensitive detector. The neutron wavelength was chosen such that the [211] Fe planes would scatter diffracted intensity over approximately 90˚. The specimen was rotated and translated in this geometry, such that the sampling volume was scanned across this cross-section allowing the elastic (residual) strain to be determined from the small shifts in scattering

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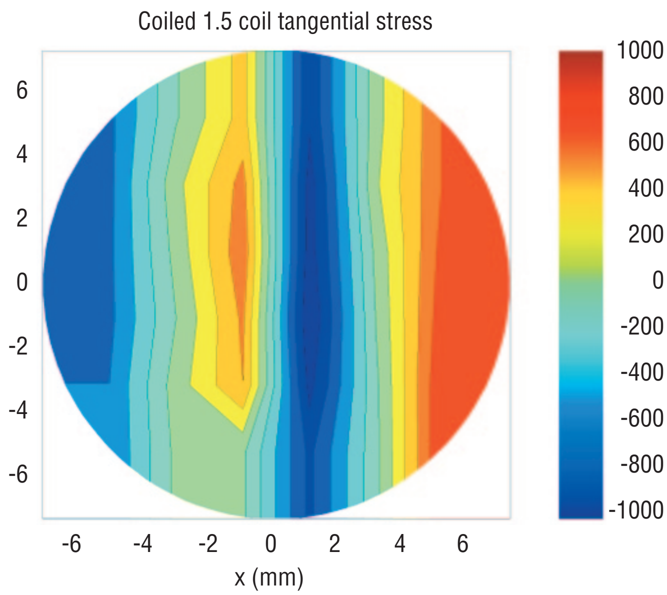


**FIGURE 2. Contour map of the residual stress in the direction of the length of the coiled bar stock, plotted on the bar stock cross-section. With reference to Fig. 1, this is the tangential direction. This map represents the as-cold-coiled spring. The left and right side of the map represent the convex and concave sides respectively.**

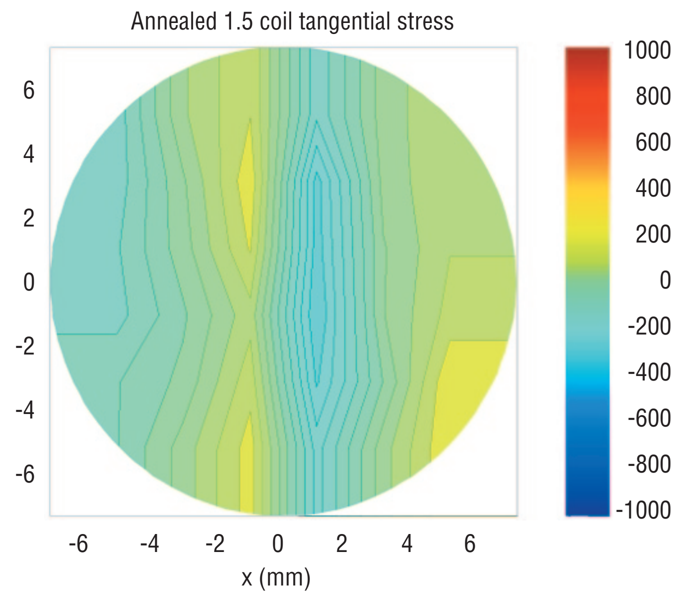


**FIGURE 3. Same as Fig. 2, these data representing the as-tempered spring. The data for the as-bulldozed spring, though not given here, look essentially the same.**

angle. This was done in three mutually perpendicular directions. These strain measurements allowed us to calculate the residual stress in three perpendicular directions from the equations published by Allen *et al*. [1] in each of the three specimens. For every specimen, the stress free lattice parameter was determined on the basis that the net force on the cross-section under investigation had to be zero.

From these experiments a set of interesting observations can be made. First is the notion that the residual stress pattern across the wire stock in the as-coiled spring is very pronounced and exactly matches what one would expect when a cylindrical bar is plastically bent into a hoop, a process much resembling helical coiling. With reference to Fig. 2 we note essentially uniaxial residual stress in the length direction of the original wire stock. Through the diameter of the stock, the stress goes from highly compressive at the convex side to highly tensile at the concave side. On its way through the cross-section the stress level changes sign three times, while the maximum compressive and tensile stresses are –600 MPa and +800 MPa respectively. For the tempered and bulldozed specimens the pattern is roughly the same, albeit at a much reduced level. The stress range being from –170 to +160 MPa as depicted in Fig. 3.

The uncertainties in these stress levels are around ± 30 MPa. This means that the bulldozing process does not introduce additional residual stresses, a fact that can be well understood considering that the plastic deformation under pure torsion is essentially uniform and thus cannot contribute to the residual stress state.

These results will allow Ford to correlate their model predictions and X-ray residual stress measurements to the complete residual stress field. This constitutes a powerful tool in optimizing the parameters of the spring manufacturing process.

## REFERENCES:

[1] A. J. Allen, M. T. Hutchings, C. G. Windsor, and C. Andreani: "Neutron Diffraction Methods for the Study of Residual Stress Fields," Advances in Physics, **34**, 445-473 (1985).