Influence of peening parameters, coating temperatures and operating loads on Residual stresses of shot-peened barrel springs *

W. Hutter, Bayerische Motoren Werke AG, Munich, FRG
K. H. Kloos, Institut für Werkstoffkunde, Darmstadt, FRG

Barrel springs

In recent years, a clear trend has developed towards increasing the strength of vehicle suspension springs by the greater utilisation of the properties of materials. This trend evolved from the desire to save weight. A compact version of a spring with high load capacity is the barrel spring /1/, which like all other vehicle suspension springs is shot-peened in order to increase its operating life. BMW uses a barrel spring of this type on the rear suspension of its 3 series cars., Fig. 1 illustrates the final assembly.

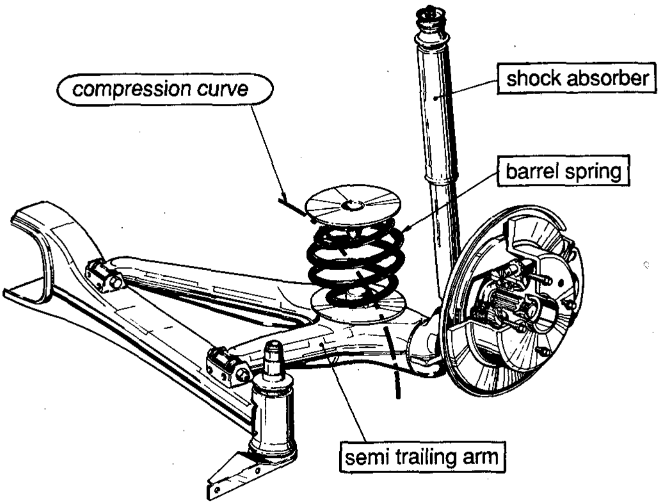


Fig. 1: Final assembly position of the barrel spring

Apart from the two centre coils, the barrel spring has a variable wire and coil diameter. This design produces a combination of linear and progressive characteristics. The progressive rate permits high vehicle payloads, with the vehicle's static load height changing only slightly. The shape of the barrel spring that is utilized during this investigation (Material: 55 Cr 3), was reached by warm working.

Influence of spring compression on bending and torsional stresses

In the technical application of vehicle springs, a distinction is made between two fundamental suspension designs:

* Extract from a publication of a projekt of the Institut für Werkstoffkunde, Darmstadt

- On the one hand, the principle of the spring-strut axle with a coaxial arrangement of spring and shock absorber in a compact unit; apart from lateral resilience incorporated into the design, springs are only subjected to load along their centre line. This load will be referred to below for the sake of brevity as parallel spring compression.
- On the other hand, versions with a seperate spring and damper system, where the springs bear on trailing arms or wishbones and are consequently subjected to an arc-pattern load (system spring compression).

The spring used by BMW thus complies with the system spring compression principle. To assess the influence of residual stresses revealed by shot-peening on the endurance of barrel springs, the operating stresses occurring in practice (bending and torsional stresses) must always be known. These cannot be defined by the computing programs currently available.
In order to obtain detailed knowledge of these operating stresses, 144 strain gauges were attached to a barrel spring and the stresses calculated at the various coils in various stages of spring compression (parallel and system).
Fig. 2 demonstrates that in the case of system spring compression a bending stress pattern passing through zero occurs (shaded), whereas in the case of parallel spring compression a dynamic bending stress pattern occurs (cross-hatched).

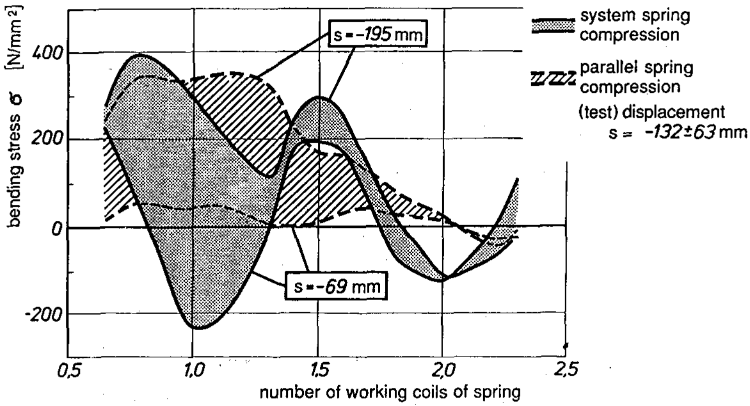


Fig. 2: Barrel spring bending stresses with parallel and system spring compression

The main load on barrel springs, as on coil springs, is generated by a torsional moment. Torsional stresses (Fig. 3) are therefore much higher than bending stresses. There is not such a great difference in their patterns for system and parallel spring compression as in the case of bending stresses.
The pattern for bending stresses leads to the following requirement:
barrel springs must be tested in system conditions, as the loads developed during parallel spring compression are not vehicle-specific and part's operating life on the car can only be determined to a limited extent.

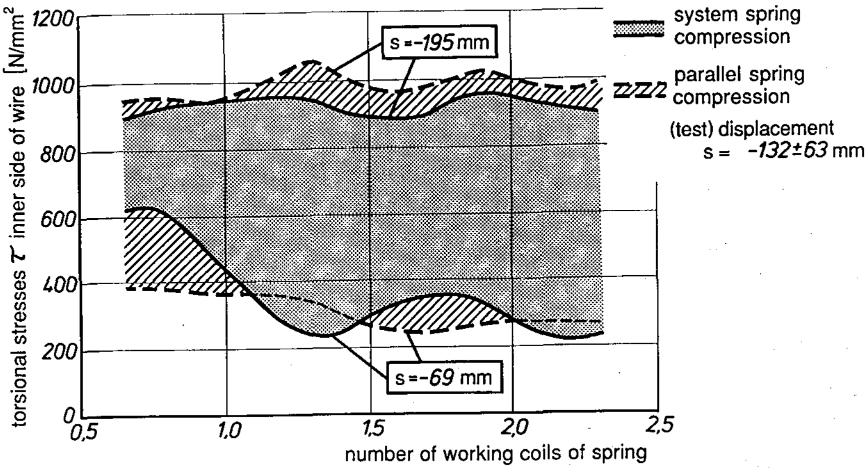


Fig. 3: Barrel spring torsional stresses with parallel and system spring compression

Shot-peening parameters

The influence of various peening parameters on the structure of residual stresses in barrel springs was investigated (Table 1).

shot	shot velocity (m/s)	exposure time (s)
A S 230	65	10 / 20 / 30
	75	10 / 20 / 30
	85	10 / 20 / 30
B S 330	65	10 / 20 / 30
	75	10 / 20 / 30
	85	10 / 20 / 30
C S 390	65	30
	75	30
	85	30
S 330 plus S 230	(B 75) 65	je 30
	(B 85) 65	je 30
S 390 plus S 230	(C 75) 65	je 30
	(C 85) 65	je 30

shot peening method: wheel

shot hardness	
54 HRC	
shot	shot diameter (mm)
S 230	97%≥0,5
	85%≥0,6
	10%≥0,85
S 330	96%≥0,71
	85%≥0,85
	5%≥1,18
S 390	96%≥0,85
	85%≥1,0
	5%≥1,4

Table 1: Varying the peening parameters

It proved possible to calculate the influence of the shot, the shot velocity, the exposure time and a combination of these criteria on the structure of residual stresses from the peening parameters selected for this test. Shot-peening treatment was carried out in a test-wheel plant. If the shot-peening parameters are varied, surface roughness changes. This effect is illustrated for shot S230 in Fig. 4.

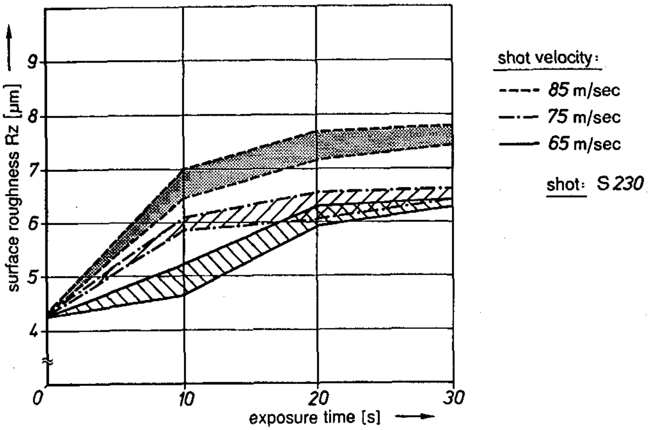


Fig. 4: Surface roughness according to exposure time and shot velocity

Surface roughness increases with higher exposure time and shot velocity. Greater surface roughness has a negative effect on endurance and corrosion resistance. For this reason, according to the intended aplication a compromise between introducing residual compressive stresses (positive) and the resultant greater level of surface roughness (negative) should be sought.

Coating temperature

Barrel springs are stove-enamelled for app. 30 minutes at a temperature of 170 - 190°C after shot-peening, to protect them against corrosion. These temperatures have a negative effect on the residual stresses generated by shot peening, as these are eliminated. The relationship between residual stresses and temperatures from 150 - 200°C for this period of time is illustrated in Fig. 5.

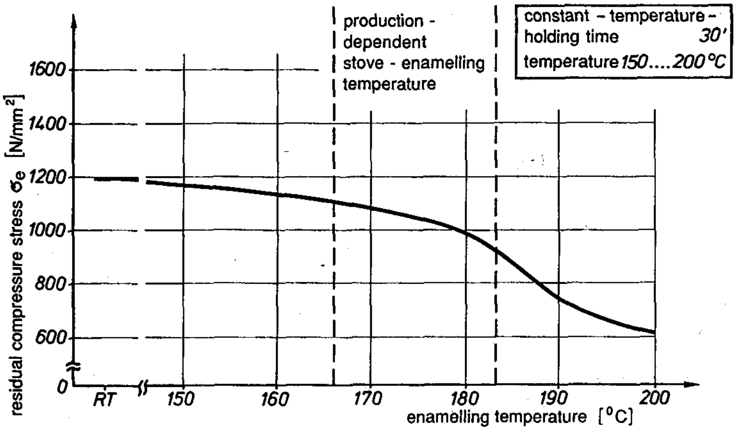


Fig. 5: Barrel spring - influence of coating temperature on residual stresses

The elimination of residual stresses has the effect of reducing the barrel spring's endurance. If springs are maintained at a temperatur of 190°C for 30 minutes, their endurance falls by app. 20 %. For this reason, stoving temperatures above 180°C should be avoid.
Ulbricht /2/ investigated the influence of temperature on the endurance of both shot-peened and untreated specimens. He determined that the endurance of shot-peened specimens fell away sharply in relation to temperature. Specimens were exposed to high temperatures for 2 hours (Fig. 6). It is not known to what extent the residual stresses changed.

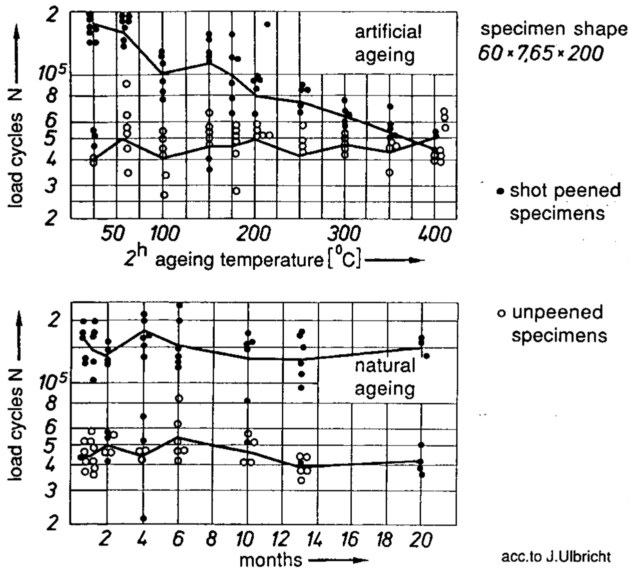
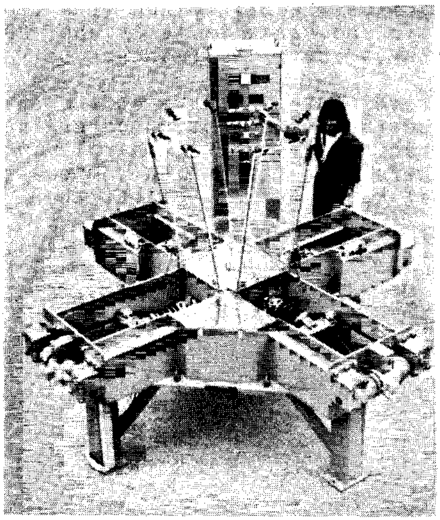


Fig. 6: Influence of ageing on shot-peened specimens (according to Ulbricht)

No deterioration in the endurance of either shot-peened or untreated specimens occurs as a result of natural ageing (lower diagram, Fig. 6).

Test rig testing

To calculate endurance, one-level test were carried out. The testing machine used (Fig. 7), was developed specifically for testing springs in conjunction with the IABG. It has now been sold unter licence to all reputable spring manufacturers in the Federal Republic of Germany /3/. The great advantages of this machine are a testing frequency of up to 15 Hz, output 4 kW, option of either system or parallel spring compression and the capacity to test four springs simultaneously. Compared with the testing machines previously used, the higher testing frequency has considerably boosted throughput and results for varying peening parameters can be processed more rapidly.



technical data:

- displacement, adjustable by eccentric: 80 ... 230 mm
- ac-drive 4 kW, 380 V
- speed 60 ... 900 min^{-1} frequency controlled
- cut-off by acceleration switch, activated by spring rupture
- spring pre-load adjustable by 4 electric double spindle drives

Fig. 7: Vehicle spring test rig for coil and barrel springs

Springs treated with varying peening parameters exhibited no ruptures in the one-level test at room temperature and testing loads of between -7560 and -2000 N at an average force of -4100 N and up to 2,5 x 10^6 load cycles. The springs tested in this way were then subjected to a 240-hour salt spray test and the above one-level test repeated. The cycles to failure for the one-level test are shown in Fig. 8 in relation to exposure time, shot velocity and shot.

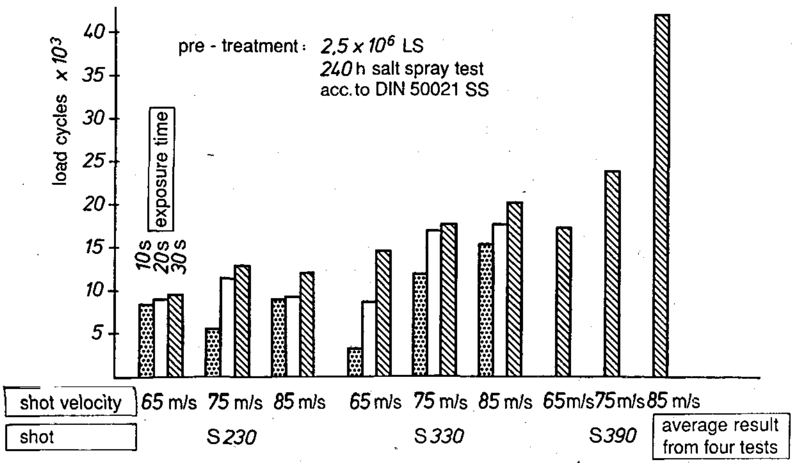


Fig. 8: Barrel spring - cycles to failure after pre-treatment in relation to shot-peening parameters

It has recently been assumed that pre-peening with a coarse peening medium, followed by peening with a fine medium, leads to increased endurance.
Pre-peening with S390 and post-peening with S230 did not prove any more advantageous than single-stage peening with S390 on the parts investigated here. This is probably due to the fact that with a coarser peening medium at the same speed and processing time, the residual stresses are generated to a greater depth than if a fine peening medium is used. Post-peening with a fine medium only generates additional residual stresses to a very shallow depth. Due to the effects of corrosion, these thin zones are penetrated very rapidly, with the effect that only the residual stresses at a deeper level boost spring endurance. Accordingly, nothing is gained by post-peening with a fine medium. Fig. 9 reveals the extent to which residual stresses change in relation to fatigue cycles. After 2,5 x 10^6 load cycles, the residual pressure stresses generated by shot peening had been reduced by app. 8 %.

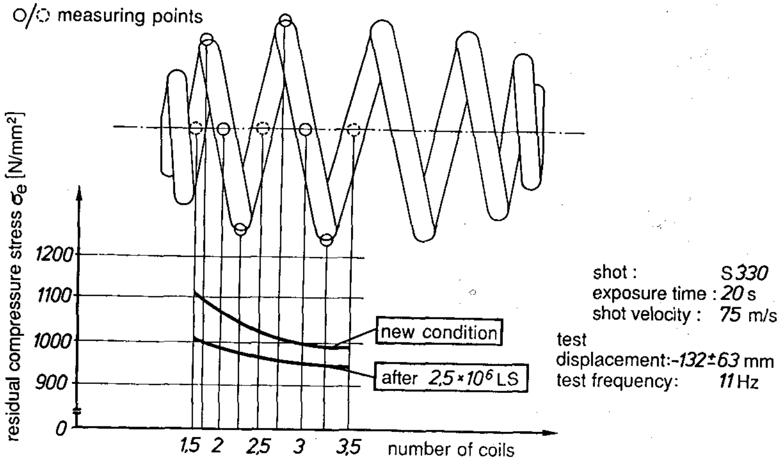


Fig. 9: Barrel springs- elimination of residual stresses under oscilating load

A particular point of interest is the magnitude of the residual stresses generated in the spring after tempering and warm-setting. With this method it is possible to determine the residual stresses generated by shot-peening.
Barrel springs were taken directly from production after tempering and warm-setting (springs compressed to a block at app. 250°C) and investigated to determine the residual stresses generated. The results are shown in Fig. 10.
The change in the residual stresses for the various turns should be noted. This is attributable to the shape of the barrel spring (varying degrees of deformation in the individual turns).
It is furthermore significant that the springs tested cooled down slowly after warm-setting (taking app. 1 hour to cool down to room temperatur), as a result of which the residual pressure stresses were partly eliminated again.

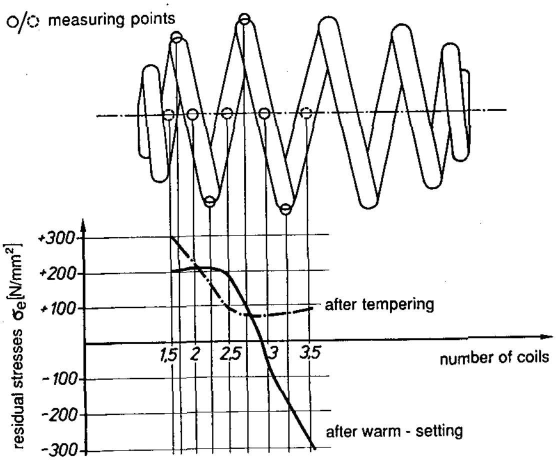


Fig. 10: Barrel spring - residual stresses before shot peening

Summary

Measurement of operating loads at various states of spring compression showed that only testing in the installed position (system spring compression) permitted distribution of stresses as occuring on the car in the barrel spring. This means that only system spring compression can provide an indication of endurance when fitted on the vehicle.
Coating temperatures break down residual stresses. The degree to which these break down is more marked at temperatures of 190°C upward, and the parts' endurance is reduced.
Oscilating load tests on barrel springs to investigate various peening parameters indicated that when subjected to realistic loads without the influence of corrosion, endurance is unaffected. However, unter the influence of corrosion, high exposure times, shot velocity and a coarser peening medium (S390 instead of S230) had a positive effect on encurance.
The results influence the production of barrel springs as follows:
- Avoidance of coating temperatures of above 180°C
- Use of a coarser shot to boost endurance
- No advantage achieved by pre-peening with S390 and post-peening with S230 under corrosion

References

/1/ A. Borlinghaus: Federn aus Drähten mit inkonstantem Drahtdurchmesser (Springs of varying wire diameter), Technische Akademie Esslingen (Esslingen Technical Academy), vehicle suspension springs seminar (1970)

/2/ J. Ulbricht: Qualitätssicherung bei der Stahlfederfertigung (Quality assurance in the production of steel springs), Automobilindustrie 12 (1967) No. 1, pp. 3 - 11

/3/ H. Hück, W. Hutter, W. Schütz: Schwingfestigkeitsprüfung von Pkw-Achsfedern (Fatigue strength testing of passenger car suspension springs), to appear in ATZ, autumn 1987