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OTTAWA August 12th, 1942.

REPORT
of the
ORE DRESSING AND METALLURGICAL LABORATORIES.

Investigation No. 1270.

(M. & S. No. 8/D)

Ram Tank Volute Springs.

(Copy No. 28.)

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Page

Abstract

ABSTRACT.

Reports of failures of the Ram tank volute springs are sufficiently numerous to warrant an investigation of its metallurgical characteristics.

Three samples examined after failure showed signs of having failed due to fatigue. The performance of a spring under repeated stress is a direct consequence of the stress at the surface and the condition of the surface.

All of the springs examined were found to be rough and deeply decarburized. Variation in hardness of the springs was also noted.

If the effects of surface condition are not considered, fatigue life is then roughly proportional to Brinell hardness.

All of the springs examined were found to be decarburized to a depth of from 0.005" to 0.015". Some of the springs varied considerably in hardness.

The prevention of further failures of these springs may be effected by one or more of the following steps:

(a) Use a heavier spring.

(b) Eliminate decarburization from the present spring, and protect surface from corrosion and abrasion.

(c) Use a steel less susceptible to decarburization (chrome-vanadium).

Elasticity, or load-movement characteristic depends entirely upon the spring design. Elastic limit of a spring depends upon elastic limit of the metal. Static loading tests, therefore, tell little about a spring.

The best proof of probable future performance of a spring is the fatigue test.

BUREAU OF MINES
DIVISION OF METALLIC MINERALS
ORE DRESSING AND
METALLURGICAL LABORATORIES

CANADA
DEPARTMENT
OF
MINES AND RESOURCES
MINES AND GEOLOGY BRANCH

OTTAWA August 12th, 1942.

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Ram Tank Volute Springs.

Introduction.

Prof. J. U. MacEwan, Consultant to Director of Metallurgy, Army Engineering Design Branch, Department of Munitions and Supply, Ottawa, Ontario, submitted six volute springs for examination. Work commenced on August 3rd, 1942.

Description of Samples:

Sample designated "A" was reported to have passed the static loading specification. Its markings were:

PCE - C73927
ORD - Q24250
HT - 59M141

Sample designated "B" was reported to have failed the static loading specification. Its markings were:

FCE - 3927
ORD - 16-139
HT - 455

Sample designated "C" was reported to have run 1,644 miles in a Ram tank without failure. Its markings were:

PCE - C-73927
ORD - Q13060
HT - 56L328

Samples "D", "E" and "F" failed in service apparently due to fatigue.

"D" PCE - C-75927
ORD - Q13060
HT - 56L329

"E" FLY
C-78927A4
HT-606241
E - 442

"F" CEC - 73927
ORD - Q13060
HT - 56L32.

(Continued on next page)

(Description of Samples, cont'd) -

Figure 1.

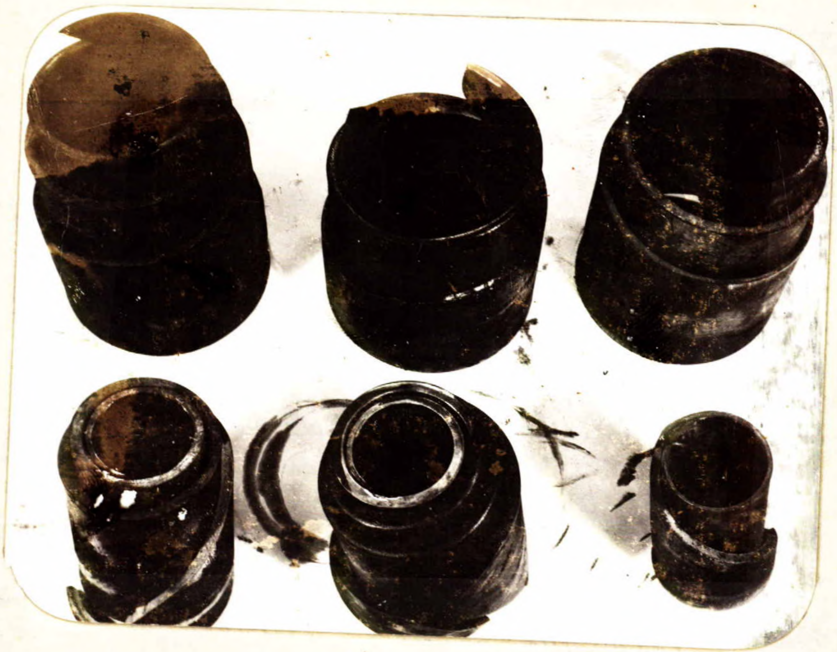
VOLUTE SPRING.

Approximate physical dimensions:

Weight - 50 pounds
Diameter at base - 7 inches
Diameter at pointed end - 3 "
Number of coils - 6
Height - 12½ inches.

Nature of Samples:

Figure 2.



"D", "E", and "F", AS RECEIVED.

Note spiral course of fracture. Compare with Figure 21. Failures occurred within the first three coils from the centre.

Figure 3.

Typical rough surface on all specimens.

(Nature of Samples, cont'd) -

Figure 4.

Fracture of Spring "D".

Figure 5.

Fracture of Spring "E".

Figure 6.

Fracture of Spring "F".

(Nature of Samples, cont'd) -

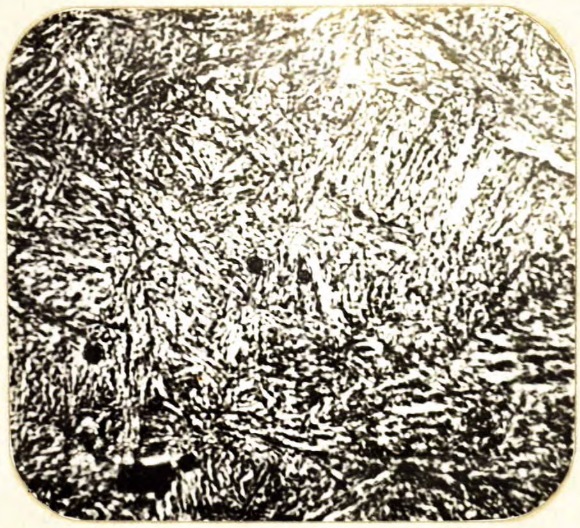
Figures 4, 5, and 6 attempt to show the nature of the fractured surfaces, which are characterized by smooth areas, indicating the gradual growth of a crack and rough areas which were caused by rupture after the fatigue crack reduced the section below its load-carrying capacity.

Microstructure:

Figure 7.

"C" X1000 nital etch.
V.H.N. 285.
Showing pearlite and ferrite.

Figure 8.



"C" X1000 nital etch.
V.H.N. 372.
Sorbitic Structure.

(Continued on next page)

Figure 9.

X100, nital etch.
Sample "C"
Sorbite.

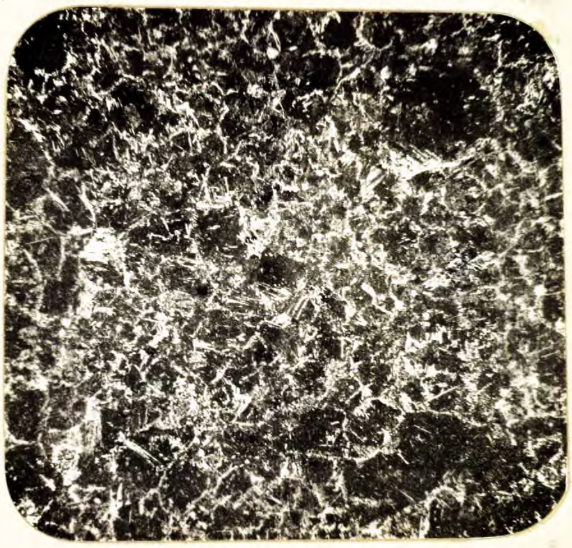
Figure 10.

X100, nital etch.
Sample "C"
Ferrite network.

Figure 11.

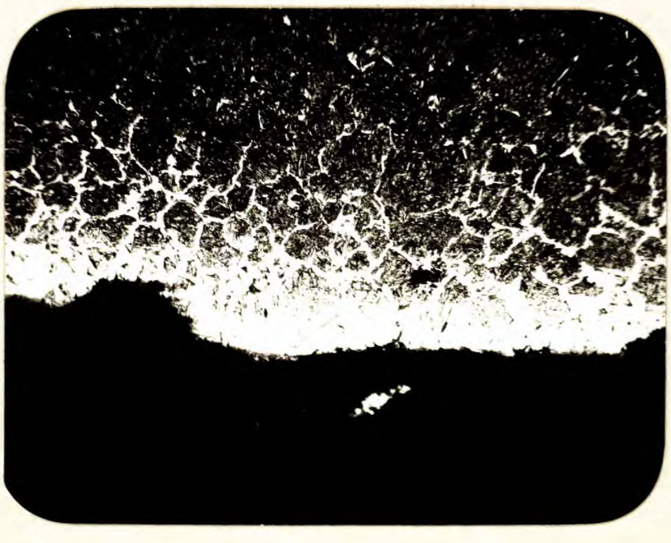
X100, nital etch.
Sample "A"
Sorbite.

Figure 12.



X100, nital etch.
Sample "A"
Ferrite network.

Figure 13.



X100, nital etch.
Sample "A"
Above decarburized edge is typical of all springs examined.

(Microstructure, cont'd) -

Samples "A", "B", and "C" all show that part of the spring had been properly quenched, and other parts had been improperly quenched. The ferrite network shown in Figures 7, 10 and 12 is associated with low hardness and hence low fatigue strength.

Samples "D", "E", and "F" showed martensite and sorbite structures, indicating good quenching practice. Unfortunately, decarburization nullified the effects of the good interior structure.

Hardness:

Carefully prepared specimens were cut from the springs, a segment from the 2nd and 3rd coil (counting from the centre) was removed and polished. Hardness at the centre of the strip is recorded on pages 9 to 14. Effect of decarburization on hardness is shown in Figure 20.

Table I shows the hardness of "D", "E", and "F" near the fracture. (Table I appears on Page 15).

RAM TANK SPRING
HARDNESS ON TRANSVERSE CROSS-SECTION

3rd coil

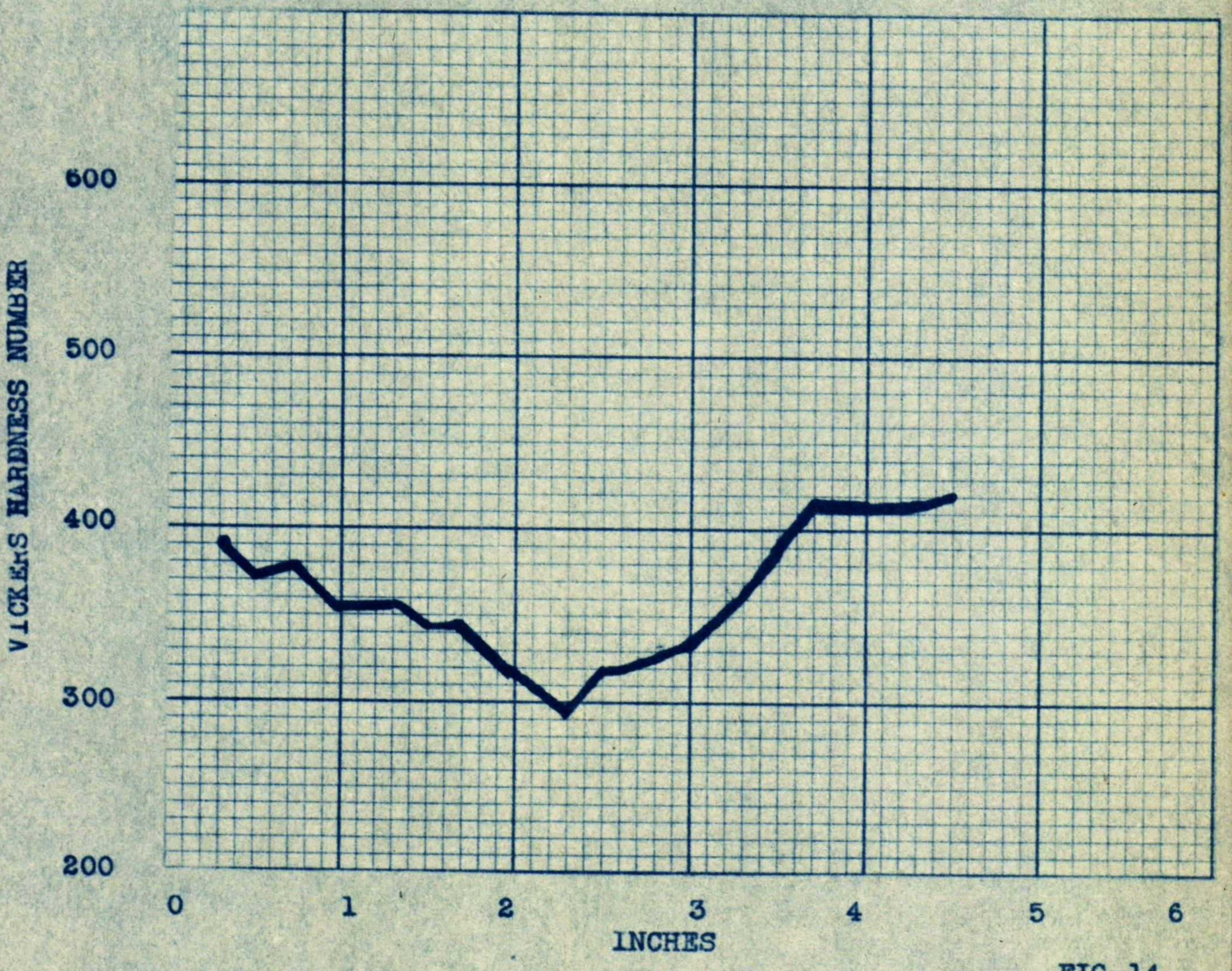


FIG. 14
SAMPLE "B"

RAM TANK SPRING
HARDNESS ON TRANSVERSE CROSS-SECTION

2ND COIL

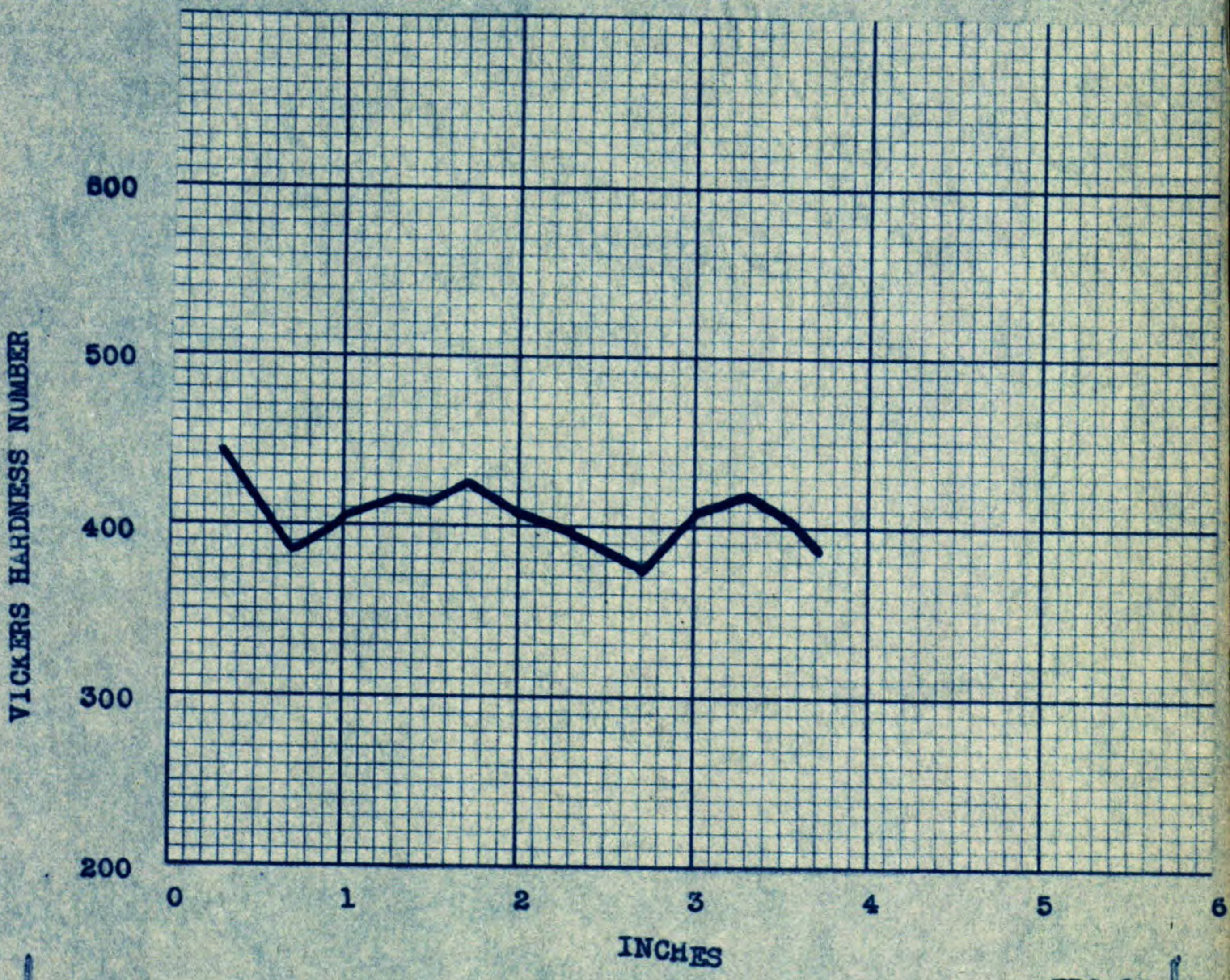


FIG.15
SAMPLE "S"

RAM TANK SPRING
HARDNESS ON TRANSVERSE CROSS-SECTION

~~4TH~~ 2ND COIL

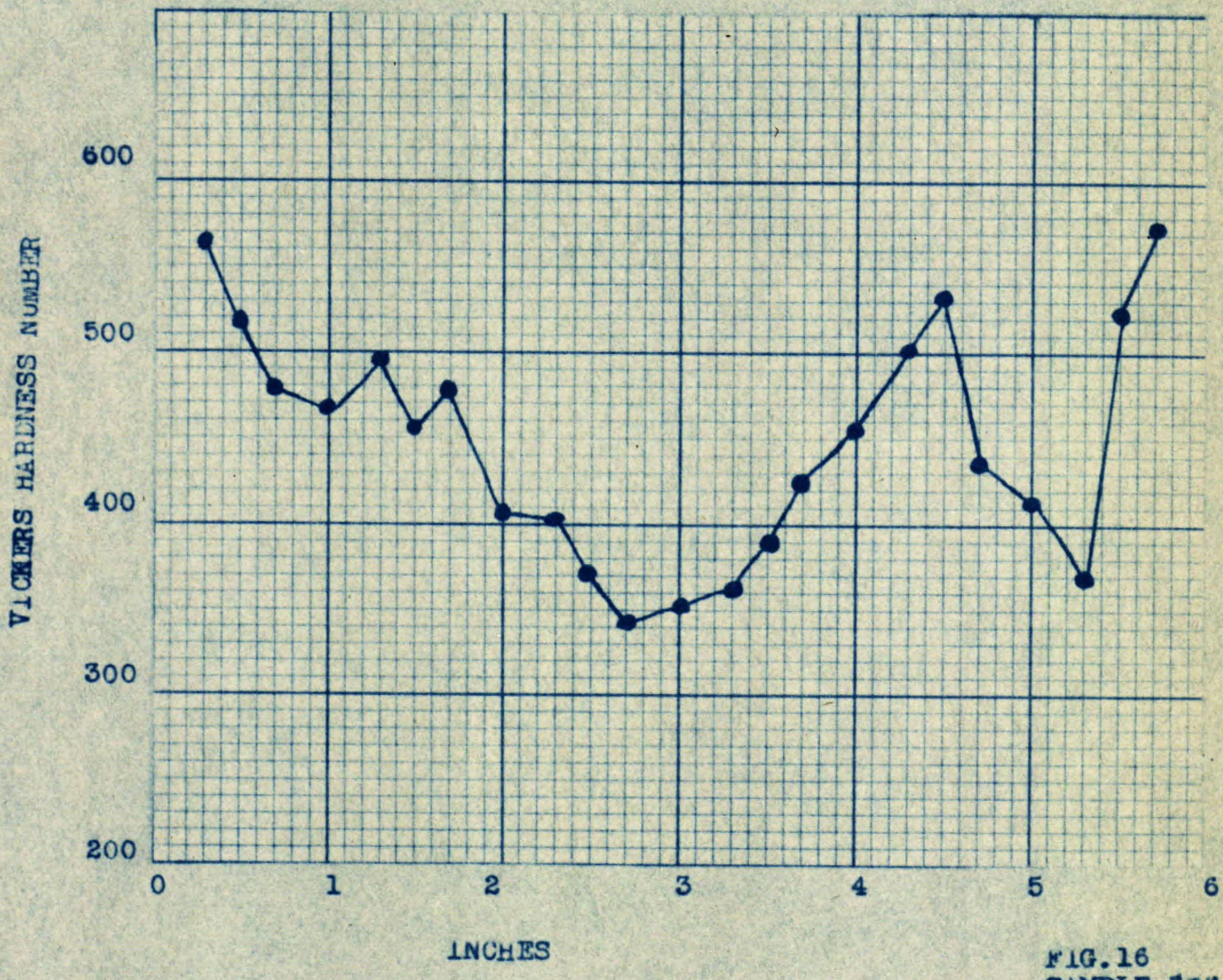


FIG. 16
SAMPLE "C"

RAM TANK SPRING
HARDNESS ON TRANSVERSE CROSS-SECTION

~~7TH~~ 3RD COIL

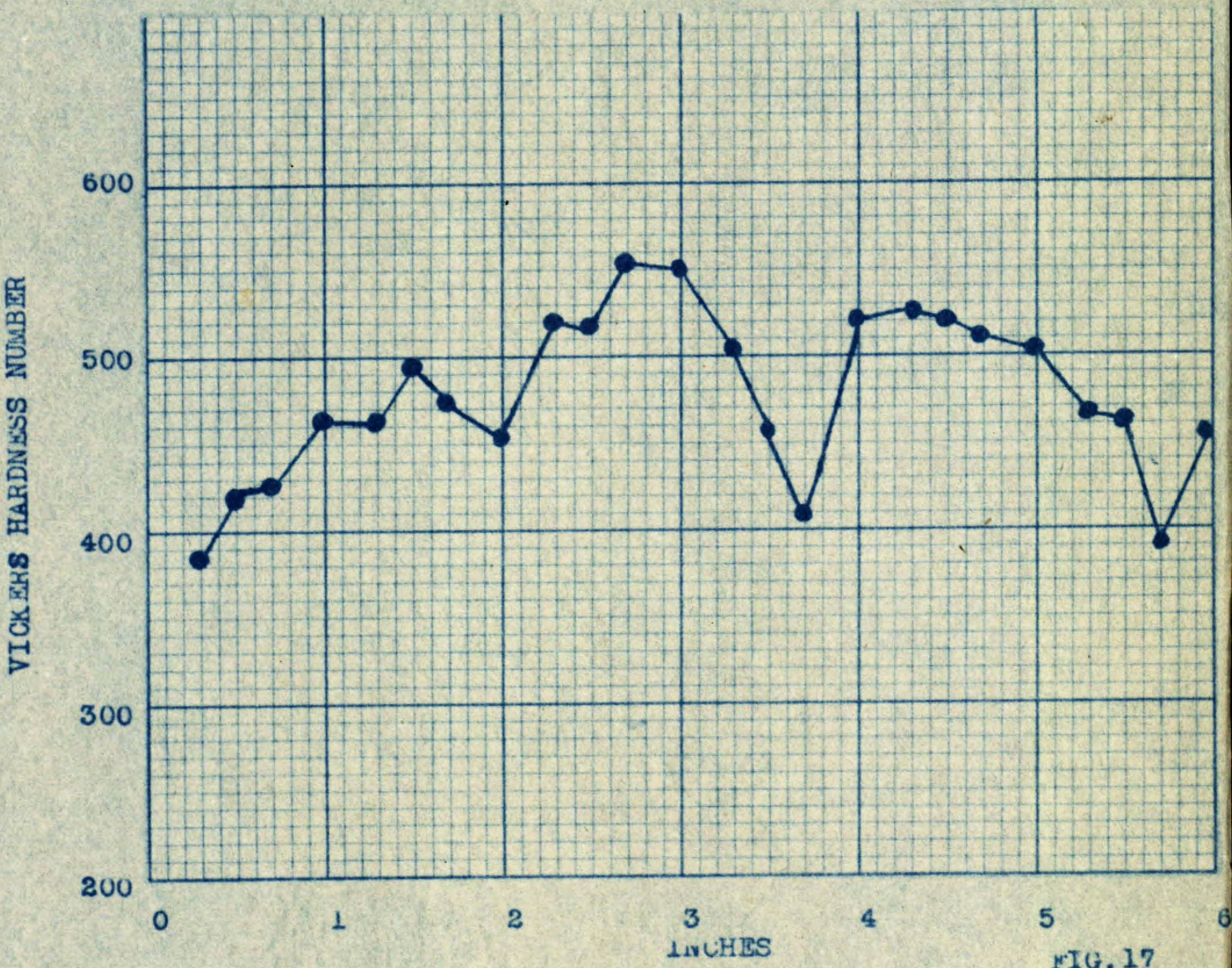


FIG. 17
SAMPLE "C"

RAM TANK SPRING
HARDNESS ON TRANSVERSE CROSS-SECTION
PASSED

~~4TH~~ 2ND COIL

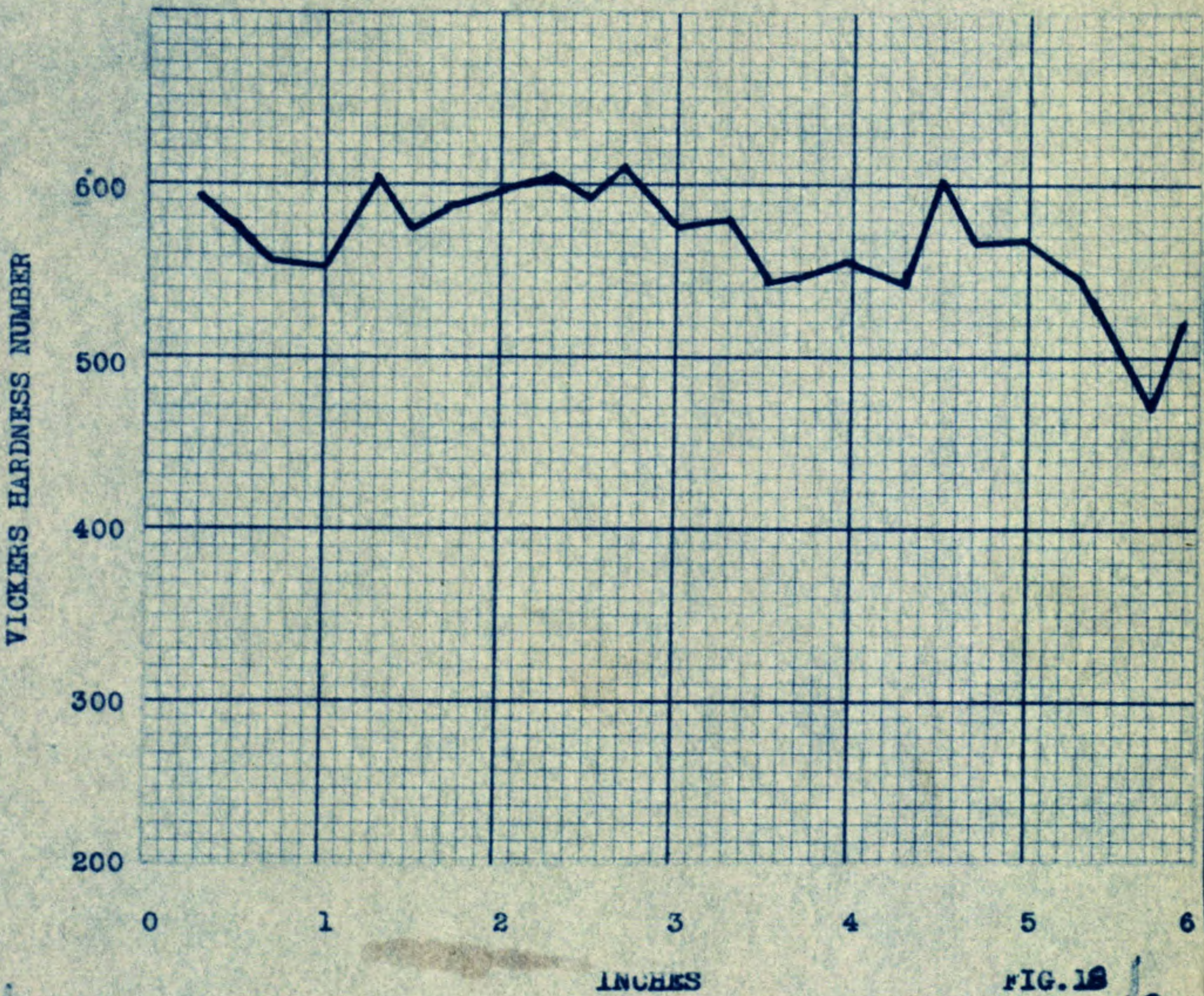


FIG. 18
SAMPLE "A"

RAM TANK SPRING
HARDNESS ON TRANSVERSE CROSS-SECTION
PASSED

~~7TH~~ COIL
3RD

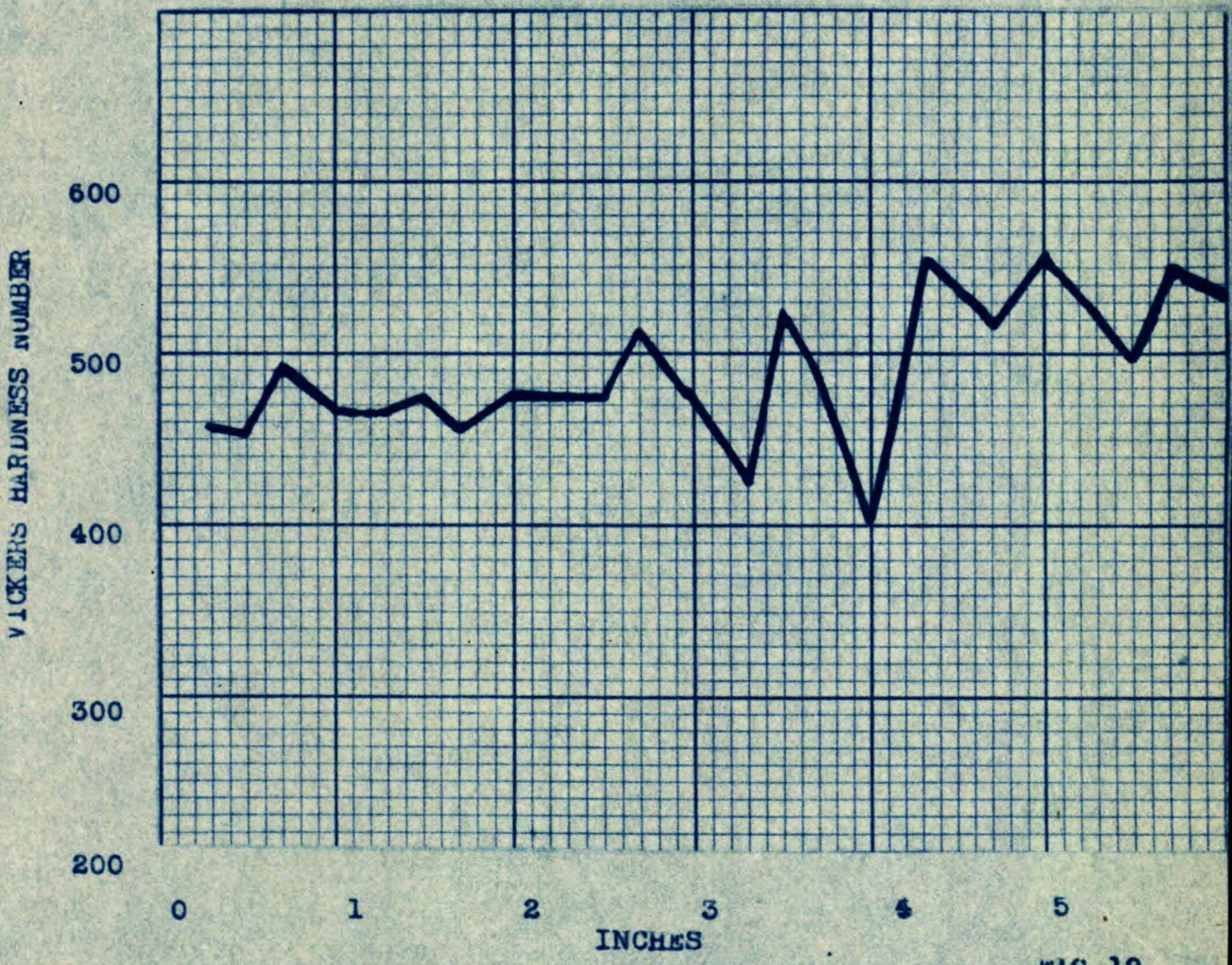


FIG. 19
SAMPLE "A"

[redacted]

TYPICAL HARDNESS CURVE
SHOWING EFFECT OF DECARBURIZATION
SAMPLE "B"

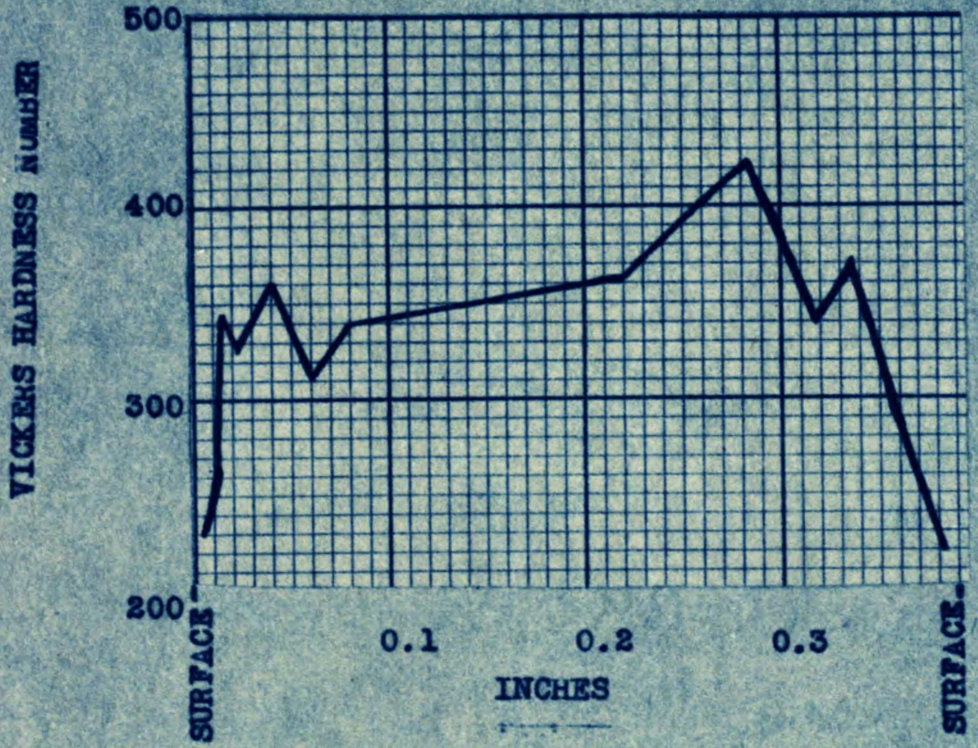


FIG.20

Decarburization:

Table I.

Sample	Position in strip	V.H.N.	Type of microstructure	Depth of free ferrite, inches
"C"	Edge	372	Sorbite	.012
	Centre	285	Pearlite and ferrite	
"A"	Edge	543	Sorbite	.011
"B"	Edge	441	Sorbite	.015
	Centre	418	"	.010
"D"	Edge	496	Martensite	.008
	Centre	470	"	.006
"E"	Edge	505	Sorbite	.005 - .011
	Centre	515	"	.012
"F"	Edge	520	Martensite	.006
	Centre	478	Martensite and ferrite	.007

Figure 21.

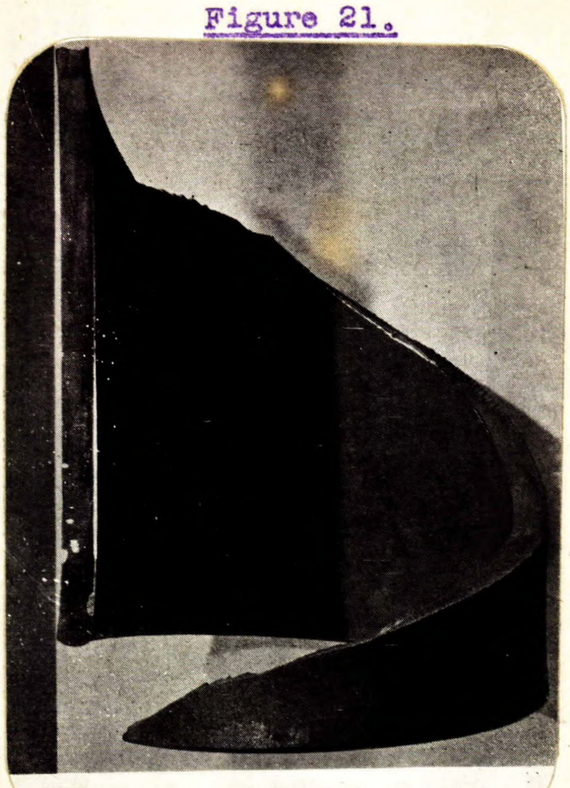
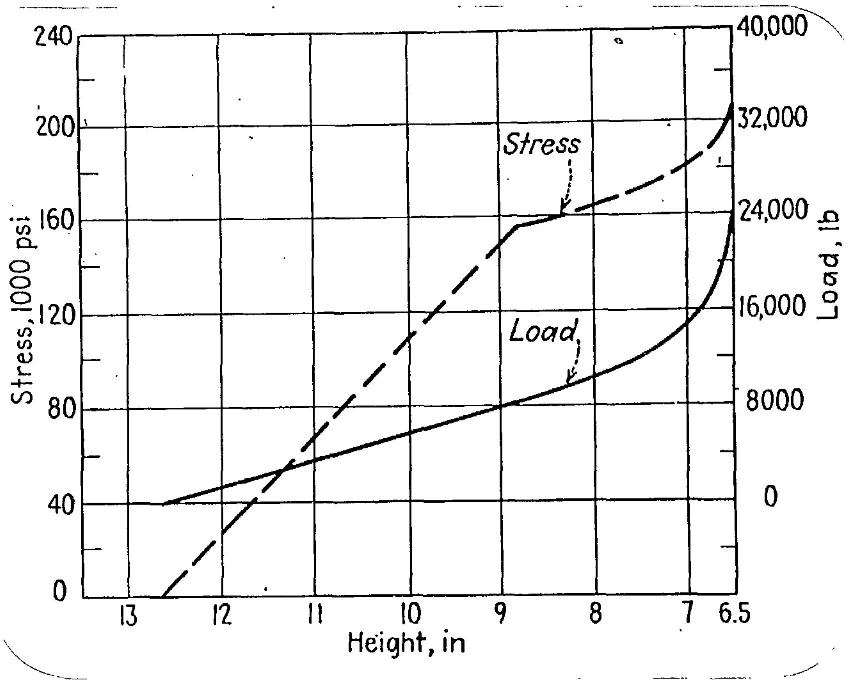


Fig. 29 – Typical spring failure resulting from life-test w

TYPICAL FATIGUE FRACTURE.
(S.A.E. Journal, June, 1942).
Note the similarity between this and Figure 5.

Figure 22.



(S.A.E. Journal, June, 1942).

The above curve is very similar to that obtained with the volute springs mentioned in this report. Note that in the lower ranges one ton additional weight reduces the height of the spring approximately one inch. This curve is determined by:

(1) Design of spring.
(2) Modulus of elasticity of steel.

Modulus of elasticity of steel is a constant irregardless of microstructure or hardness. Therefore, the only way to change the slope of the curve of Figure 22 is to change the design of the spring.

As the load is increased, a point will be reached at which permanent set or distortion is obtained. This is the elastic limit of the spring and is dependent upon the hardness of the metal. Static loading, therefore, tests design and hardness of the spring.

(Continued on next page)

(Decarburization, cont'd) -

Q. Can the future performance of a spring be predicted from a knowledge of design and hardness only?

A. No.

Q. What is the best way to evaluate future performance of a spring?

A. If possible, proving ground tests, or fatigue tests. Auxiliary metallurgical tests based on fatigue and service test results may be used, such as:

(1) Depth of decarburization.
(2) Smoothness of surface.
(3) Depth-hardness relationship.
(4) Inclusions.

REVIEW OF SOME CURRENT LITERATURE ON SPRINGS.

Service Expected of Springs:

Springs are ordinarily supposed to be subject to alternating stresses below their elastic limit. High fatigue strength is therefore desirable. Hankins and Becker (1) have shown that fatigue limit when uninfluenced by surface conditions was roughly proportional to the Brinell hardness. Dr. T. Swinder (Sheffield) pointed out that for road vehicle springs fatigue is not the only type of service. Impact loads are encountered also; therefore, there is an upper limiting hardness, beyond which impact strength is too low.

(3) "The elasticity of a spring depends upon its dimensions not upon the physical properties of the steel." This is due to the fact that the modulus of elasticity for all steels is

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(1) The effect of Surface Conditions Produced by Heat Treatment on the Fatigue Resistance of Spring Steel, G. A. Hankins M. L. Becker, Journal, Iron and Steel Ins., 1931, Vol. II.

(3) Heat Treatment of Steel by Sherry.

(Service Expected of Springs, cont'd) -

about the same. Sterne(2) has shown in great detail the relationship between design and elasticity in volute springs of the type described in the previous report.

TEST TO DETERMINE SPRING PROPERTIES.

Static Loading:

It is generally specified that a load of X pounds shall be applied and this load must depress the spring from Y to Z in length. Release of the load should result in the spring length changing from Z to Y. Repeated loading up to 25 times should result in no permanent change in the length of the unloaded spring.

The test determines only two things about the spring: the elasticity (which is dependent upon the design), and the elastic limit (which is dependent upon hardness). The true elastic limit of the spring is not obtained, but assurance is obtained that it is above a specified minimum.

Static loading therefore tests only design and hardness.

Fatigue Testing:

Since most spring failures are attributed to fatigue and impact, it is obvious that static loading alone does not give sufficient evidence for the acceptance of a spring. Bernard Sterne(3), referring to the testing of volute springs, says:

> "As a proof for performance results which may be expected from a volute spring design, the life testing of the springs is considered indispensable."

Sterne also states that the volute spring will give proper

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(2) "Characteristics of the Volute Spring," S.A.E. Journal June 1942, Bernard Sterne, Chrysler Corpn.

(Fatigue Testing, cont'd) -

service only if it has been "bulldozed" or compressed under a load exceeding its elastic limit. A machine for fatigue testing volute springs is described in the S.A.E. Magazine for June, 1942.

Drop Impact Test:

Flexing a spring by a gradually applied load and by a dropped weight are two entirely different test methods. The first is pure fatigue, the second method introduces impact loading.

Fatigue and repeated impact tests are the only positive proof of serviceability in volute springs.

-

Metallurgical Tests:

Tatnall (3) considers Brinell hardness to be the most important metallurgical factor in springs. Woldman and Dornblatt (4) refer to silico-manganese steel being used for leaf springs, shuttle springs, and recoil springs at a Brinell hardness of 600.

Physical properties reported are:

Ultimate strength - 325,000 p.s.i.
Yield point - 200,000 "
Elongation - 20 per cent
Reduction of area - 50 "

The hardness selected for a given service will depend upon service conditions. Although fatigue resistance increases proportionally with hardness, impact strength decreases. For this reason the American Society for Metals recommends that

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(3) "Factors in the Fatigue of Helical Springs", Rodman R. Tatnall, A.S.M.E., April 1940.

(4) "Engineering Alloys," by Woldman & Dornblatt, A.S.M. publication.

(Metallurgical Tests, cont'd) -

heavy springs of silico-manganese steel be made to hardness range of 363-429 Brinell (383-450 Vickers hardness). Field tests would indicate if springs were too soft (by fatigue failures) or too hard (by impact failures).

Surface Condition:

Authorities are unanimous on the importance of surface condition on spring life. Peche and Clyne(5) state that corrosion and decarburization are the most serious causes of spring failure.

Rough surfaces aid in the formation of fatigue cracks.

The British Springs Research Committee concluded that most large springs did not reach their maximum physical properties due to surface defects.

Hankins and Becker(6) showed that ordinary hot-rolled and heat treated springs had only one half of the fatigue resistance of polished springs with no decarburization.

Hankins and Mills(7) demonstrated that resistance to repeated impact is lowered by the irregular decarburized surface which is present on a normal heat treated spring plate.

The American Society for Metals Handbook points out that decarburization as much as 0.003" seriously impairs spring properties.

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(5) Hot formed Mechanical Springs, Manufacture of Life Metal Progress, May, 1936.

(6) The Effect of Surface Conditions Produced by Heat Treatment on the Fatigue Resistance of Spring Steels, Journal of the Iron & Steel Institute, 1931, Vol. II.

(7) The Resistance of Spring Steels to Repeated Impact Stresses, Hankins & Mills Journal of the Iron & Steel Institute No. 1, 1935.

Recommended Heat Treatment:

The A.S.M. Handbook recommends that in making large flat springs of silico-manganese steel the following should be noted;

(A) A forming temperature of 1800° F. should not be exceeded.

(B) The spring should be removed from the oil quench at a temperature just below 300° F.

(C) Quenching oil should be well circulated and kept at a temperature of 100° - 140° F.

(D) Normalize at 1600 - 1625° F.

(E) Quench into oil from 1575 - 1600° F.

(F) Temper at 850 - 1050° F.

Peche and Clyne(5) warn against quenching direct from the forming operation. Such a procedure results in a coarse structure unfit for severe service.

A.S.T.M. Specification A 59-39:

Silicon Manganese Steel For Springs.

		Per cent
Carbon	-	0.55 - 0.65
Manganese	-	0.60 - 0.90
Phosphorus (max.)	-	0.045
Sulphur (max.)	-	0.045
Silicon	-	1.80 - 2.20

Decarburizing Properties:

Andrews and Richardson(8) have shown that silico-manganese steel decarburizes more readily than either carbon steel or chrome-vanadium steel.

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(8) An Investigation of Spring Steels, V. H. Andrew and G. T. Richardson, Journal of the Iron & Steel Institute, No. 1, 1935.

Prevention of Decarburization:

Sanders(4) referred to the practice of replacing carbon in decarburized surfaces by painting with graphite before reheating. Where springs are wound, cooled, and then heated for quenching, it is possible to reduce decarburization by using a controlled atmosphere.

The following discussion of springs is taken from Appendix 20 in:

PREVENTION OF THE FAILURE OF
METALS UNDER REPEATED STRESSES

A Handbook Prepared for the
Bureau of Aeronautics
Navy Department

by

Battelle Memorial Institute.

Steel springs are designed to carry very high loads. They must have high elastic strength and necessarily they are very hard and strong--usually over 200,000 p.s.i. tensile. They are, therefore, particularly susceptible to notches as will be recalled by reference to Figure 58. Since in any type of spring the stress is highest at the surface, the strength of the surface layer and its freedom from notches control the fatigue strength of the spring. In the heat treatment of springs, the material has ordinarily been heated in open furnaces which produces a decarburized surface layer. Such spring stock is, therefore, ground deeply in order to remove it completely, the relatively weak surface layer fails at ordinary service stresses, a crack starts and promptly propagates through the spring.

The polished endurance limit of spring steels, tested with the breaking section necked down as to come below the traces of decarburization that may still be left on the surface, may be very high. When the steels are made into springs and the springs

(Prevention of Decarburization, cont'd) -

tested, the endurance of the springs almost invariably is far below what the steel appears to be capable of. Appendix 6 probably gives the clue, i.e., that the spring has a considerable area of stressed surface, compared to the tiny area of an endurance specimen, and, with steels at so vulnerable a hardness as in springs, complete elimination of all surface stress-raisers or weak spots is improbable in the actual springs. A single weak spot where decarburization has occurred, too deep to be entirely removed by grinding, is sufficient to bring the whole spring down to that level of weakness.

The evil effect of decarburization has long been recognized. Indeed, the usual choice of chromium-vanadium steels for springs for severe duty over those of the cheaper silicon-manganese steel, although often phrased on the basis of some ill-defined "superiority in fatigue," has its primary basis in the lesser tendency of the former to decarburize in heating.

It is difficult to avoid decarburization during heating prior to the hot rolling of rod used for springs. After centreless grinding of the rod for complete removel of the soft skin, however, heating for quenching can subsequently be done without decarburization by the use of the correct controlled atmosphere.

Boegehold's comments on coiled springs deserve quoting. He says, "The coil spring for the individually suspended front wheels in the 'knee action' is an interesting metallurgical study because of the high stresses induced from the loads imposed. When the wheel moves upward to the bump position the stress in a typical spring is 117,000 p.s.i. in torsion--almost up to the elastic limit. Naturally, considerable movement accompanies this stress. There are no other parts of the car stressed as highly as the springs and we can rest assured that there probably never will be, because with that amount of stress there is also a proportionate deflection. It is quite obvious that we would be unable to tolerate deflections in our other operating parts of the same order as experienced in the springs.

"Any part stressed as near to its elastic limit as a spring is, must not have any surface irregularities to cause stress concentration. This is responsible for several interesting features associated with the manufacture of coil springs. First, the steel rod is ground to remove all decarburization. It is then heated for coiling, the temperature being held down around 1450° to 1500° F. to be sure that no decarburization occurs in this operation. This is very important, because a spring decarburized a few thousandths of an inch at the surface will take a gradual and continuous set in service and will have a short life when failure occurs. A consideration of the properties of the decarburized surface layer will readily explain why this is so; it has a strength of only 45,000 to 50,000 p.s.i. in tension, or 60 per cent of that figure in torsion. When this surface metal (which receives the maximum stress) is subjected to 117,000 p.s.i. torsional stress repeatedly in going over the bumps, there is bound to be a fatigue crack developed which travels inwards to the depth of the decarburized layer. This crack then acts as a notch to cause stress concentration, which results in overloading and cracking the full-strength material immediately under the decarburized layer.

"A properly processed spring will have, as one of the manufacturing operations, a 'setting down' which consists of closing the spring several times until it takes a slight permanent set. Unless this is done even a properly heat-treated spring will take a permanent set in service. In addition to this,

(Prevention of Decarburization, cont'd) -

springs are sometimes shotblasted to cold work the surface slightly. This not only obliterates any surface imperfections which might have acted as stress raisers but the cold work also increases the strength of the surface layer and prolongs the life."

Every discussion of fatigue of springs and especially of aircraft engine valve springs emphasizes the same points. Compare Johnson, McAdam, Clyne, Arnstein and Shaw, Hunlich and Pungel, Pomp and Hempel, and Tatnall. Zimmerli remarks that, when applied to sound steel free from seams, shotblasting has done more to improve the endurance of springs than has the selection of special alloy steels for springs. Swan, Sutton and Douglas comment on greater decarburization of silicon-manganese over chromium vanadium steel, and the bad effect of inclusions, which they say, tend toward production of minute surface cracks on quenching. Lehr brings out the same points and suggests the possibility of nitriding springs to improve the surface condition though he gives no data on them. Harder shows photos of nitrided springs for Diesel engines.

Weibel reports for a tempered 0.65 per cent carbon valve spring wire 0.225 in. diameter, of 204,000 p.s.i. tensile, 166,000 torsion, the following:

Endurance Limit.

	Rotating beam	Reversed torsion
As received........................	67,000	56,000
Ground to 0.221 in.	81,000	54,000
Shotblasted........................	85,000	61,500 +
Shotblasted and blued 30 min. at 500° F. to relieve cold-work stresses........................	83,000	65,000 +

Blank says that the use of tungsten carbide drawing dies to avoid die marks, the use of controlled atmospheres to

(Prevention of Decarburization, cont'd) -

avoid decarburization and the use of light shotblasting are all beneficial. The proper degree of shotblasting raised the endurance of actual springs from a range of 20,000 - 95,000 p.s.i., to one of 20,000 - 115,000. Morrison gives similar data for the improvement of patented wire by the avoiding of surface defects.

The evil effects of any sort of surface seam or notch on springs has been mentioned in the test. Not only the obvious notches, but also sharp edges, are harmful. Hendrickson points out the benefits of smooth edges on leaf springs.

Because springs are tempered at low temperatures to retain strength and hardness, they are prone to contain internal quenching stresses.

CONCLUSIONS:

Failures of the springing mechanism of the Ram tank have been reported from England, Egypt, and Canada. Further failures might be avoided by

(a) a change in design, or
(b) a change in the spring properties.

From an examination of several springs, it is concluded that fatigue strength of the spring could be almost doubled if decarburization, rough surface, abrasion, and corrosion were eliminated.

A decision must be made whether course (a) or (b) is to be adopted. Prevention of the decarburized rough surface will involve extra equipment for grinding, atmosphere controlled furnaces for heat treating. Some protective coating may also be necessary. Copper, electro-zinc, or lead might be used to prevent corrosion. (See Figure 1). One way of eliminating decarburization is to gas carburize and thus produce a surface

(Conclusions, cont'd) -

at least as hard as the rest of the spring.

There are, therefore, several possible changes which might be made in the volute spring in order to give it longer fatigue life.

Testing procedure should be developed which will accurately predict behaviour in service. For this purpose, the fatigue test is indispensable. Static loading tests cannot distinguish between a short-lived spring and a long-lived spring.

Auxiliary tests which have been found to correlate closely with fatigue strength are:

(a) Depth of decarburization.
(b) Smoothness of surface.
(c) Brinell hardness.
(d) Discontinuities or inhomogeneity of microstructure.

The above tests could be performed on coupons cut from the unloaded outer end of the coil.

It will be noted that the assumption is made herein that spring failures are due to fatigue. Fatigue strength and resistance to repeated impact have been shown to be closely related. Three failures examined were typical fatigue fractures.

Infallible specifications can be drafted only after extensive proving-ground tests have been studied. This report has attempted to point out some of the factors which must be considered in developing a satisfactory spring.

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HHF:GHB.